Testing of State Roadside Safety Systems Volume I: Technical Report

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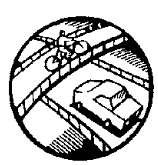

FOREWORD

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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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 a summary of the results of various laboratory, pendulum, and crash tests conducted under this study. A total of 36 full-scale crash tests were conducted, covering 12 different types of roadside safety appurtenances. The crash tests were conducted in accordance with guidelines set forth in National Coperative Highway Research Program (NCHRP) Report 230, NCHRP Report 350, and/or the 1989 American Assication of State Highway Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings,* depending on the specific appurtenance being tested. In addition, laboratory and pendulum tests were conducted on a modified breakaway modified eccentric loader terminal (MELT) post design.

This volume is the first in a series of 14 volumes for the final report. The other volumes in the series are: Volume II, Appendix A - Crash Testing and Evaluation of a Michigan Thrie-Beam Transition Design; Volume III, Appendix B - Crash Testing and Evaluation of a Guardrail System for Low-Fill Culvert; Volume IV, Appendix C - Crash Testing and Evaluation of a Pennsylvania Transition Design; 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 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.

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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 I 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.

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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I. INTRODUCTION

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.

A total of 12 roadside safety systems, listed in table 1, were crash tested and evaluated in this study. In addition, laboratory and pendulum tests were conducted on a modified breakaway wooden post design intended for use with a new Modified Eccentric Loader Terminal (MELT).

Chapter II outlines the test procedures followed in the full-scale crash testing and evaluation of these roadside safety systems. Descriptions of each of the 12 roadside safety systems crash tested and evaluated and summaries of the crash test results are presented in chapters III through XIV, one system in each chapter, as shown in table 1. Chapter XV presents descriptions of the modified breakaway wooden post designs and summaries of the results of the laboratory and pendulum tests.

The final report consists of 14 volumes. This technical report is volume I. Volumes II through XIV (appendices A through M) of the final report contain details of the crash tests for the 12 roadside safety systems and the laboratory and pendulum tests for the modified breakaway wooden posts. The volume and appendix numbers for the roadside safety systems are shown in table 1.

Table 1. List of roadside safety systems evaluated.

System	Description	Chapter	Volume	Appendix
1	Michigan Thrie-Beam Transition Design	III	II	A
2	Guardrail System for Low-Fill Culvert	IV	III	B
3	Pennsylvania Transition Design	V	IV	C
4	Washington, DC, PL-1 Bridge Rail Design	VI	V	D
5	Modified Breakaway Cable Terminal (BCT) Design	VII	VI	E
6	Minnesota Swing-Away Mailbox Support Design	VIII	VII	F
7	Single Slope Bridge Rail	IX	VIII	G
8	NETC PL-2 Bridge Rail Design	X	IX	H
9	Mini-MELT for a W-Beam Weak-Post (G2) Guardrail System	XI	X	I
10	Existing Guardrail Systems	XII	XI	J
11	MELT	XIII	XII	K
12	Modified MELT	XIV	XIII	L
13	Modified Breakaway Wooden Post	XV	XIV	M

II. CRASH TEST PROCEDURES

2.1 CRASH TEST MATRIX

The crash test procedures and evaluation criteria for the 12 roadside safety systems were in accordance with guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, and/or the 1989 American Association of State Highway Transportation Official's (AASHTO) *Guide Specifications for Bridge Railings*.[1,2,3] The specific guidelines used were a function of the type of roadside safety system being crash tested and evaluated and the applicable guidelines in effect at the time the crash tests were conducted. Table 2 presents a summary of the crash test matrix and the applicable guidelines for each of the 12 roadside safety systems.

For roadside safety systems other than bridge railings, full-scale crash testing was performed in accordance with guidelines set forth in NCHRP Report 230 at the outset of the contract in 1989. The required crash test matrix for longitudinal barriers, transitions, and terminals under NCHRP Report 230 are shown in table 3. Evaluation criteria for structural adequacy, occupant risk, and post-test vehicle trajectory set forth in NCHRP Report 230 are detailed in table 4.

In 1993, the Federal Highway Administration (FHWA) adopted NCHRP Report 350 as the official guidelines, replacing NCHRP Report 230 as the test standards. FHWA mandated that, starting in September of 1998, only highway safety appurtenances that have successfully met the performance evaluation guidelines set forth in NCHRP Report 350 may be used on the National Highway System (NHS) for new installations. Subsequent crash tests were then conducted in accordance with requirements set forth in NCHRP Report 230.

One key revision in the guidelines set forth in NCHRP Report 350 is the replacement of the 2041-kg (4500-lb) passenger car specified in NCHRP Report 230 by the 2000-kg (4409-lb) pickup truck as one of the design test vehicles. The concept of multiple performance levels is also introduced under NCHRP Report 230. The required crash tests for longitudinal barriers, transitions, terminals, and support structures under NCHRP Report 350 are shown in table 5. Evaluation criteria for structural adequacy, occupant risk, and post-test vehicle trajectory set forth in NCHRP Report 350 are shown in table 6.

All crash tests on bridge railings were evaluated according to the 1989 AASHTO *Guide Specifications for Bridge Railings*. The 1989 AASHTO guide specifications set forth three performance levels (PL-1, -2, and -3) for bridge railings. These performance levels along with their respective crash test conditions and evaluation criteria are displayed in tables 7 and 8.

Table 2. Crash test matrix and applicable guidelines.

Installation	Test No.	NCHRP 230	NCHRP 350	AASHTO
Michigan Thrie-Beam Transition Design	471470-1	Test 30		
Guardrail System for Low-Fill Culvert	471470-2 471470-4 471470-5	Test 10 Test 10 Test 10		
Pennsylvania Transition Design	471470-3	Test 30		
Washington, DC, PL-1 Bridge Rail Design	471470-6 471470-8 471470-9			PL-1 small car PL-1 small car PL-1 pickup
Modified Breakaway Cable Terminal (BCT) Design	471470-7 471470-10	Test 45 Test 45		
Minnesota Swing-Away Mailbox Support Design	471470-11 471470-12 471470-13 471470-14		Test 3-60 Test 3-61 Test 3-61 Test 3-61	
Single Slope Bridge Rail	471470-15 471470-16 471470-17			PL-2 pickup PL-2 single-unit truck PL-2 single-unit truck
NETC PL-2 Bridge Rail Design	471470-18 471470-19 471470-29			PL-2 small car PL-2 pickup PL-2 single-unit truck
Mini-MELT for W-beam Weak Post (G2) Guardrail System	471470-20 471470-23 471470-24 471470-25	 Test S31 Test S31 Test 40	Test 3-35	
Cable (G1) Guardrail W-beam Weak Post (G2) Guardrail Box-Beam (G3) Guardrail W-beam Wood Post (G4(2W)) Guardrail W-beam Steel Post (G4(1S)) Guardrail Thrie-Beam (G9) Guardrail Modified Thrie-Beam Guardrail	471470-28 471470-21 471470-22 471470-33 471470-26 471470-27 471470-31 471470-30		Test 3-11 Test 3-11 Test 2-11 Test 3-11 Test 3-11 Test 3-11 Test 3-11 Test 3-11	
MELT	471470-32 471470-34		Test 3-35 Test 3-31	
Modified MELT	471470-35 471470-36		Test 3-31 Test 3-35	

Table 3. NCHRP Report 230 crash test matrix and impact conditions for features tested.

Appurtenance	Test Designation	Vehicle Type	Impact Cond.		Impact Point	Evaluation Criteria
			Speed (mi/h)	Angle (Deg.)		
Longitudinal Barrier Length of Need	10	4500S	60	25	For post and beam systems, midway between posts in span containing railing splice	A,D,E,H,I
	11	2250S	60	15	For post and beam systems, vehicle should contact railing splice	A,D,E,F,(G),H,I
	12	1800S	60	15	For post and beam system, vehicle should contact railing splice	A,D,E,F,(G),H,I
Transitions	30	4500S	60	25	15 ft upstream from second system	A,D,E,H,I
	S31	4500S	60	15	15 ft upstream from second system	A,D,E,H
Terminals	40	4500S	60	25	At beginning of length of need	A,D,E,H,I
	41	4500S	60	0	Center nose of device	C,D,E,F,(G),H,J
	42	2250S	60	15	Midway between nose and length of need	C,D,E,F,(G),H,I,J
	43	2250S	60	0	Offset 1.25 ft from center nose of device	C,D,E,F,(G),H,J
	44	1800S	60	15	Midway between nose and length of need	C,D,E,F,(G),H,I,J
	45	1800S	60	0	Offset 1.25 ft from center nose of device	C,D,E,F,(G),H,,J

Table 4. Safety evaluation criteria for NCHRP Report 230.

Evaluation Factors	Evaluation Criteria
Structural Adequacy	A. Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.
	B. The test article shall readily activate in a predictable manner by breaking away or yielding.
	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.
	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.
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.
	F. Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in (0.61 m) forward and 12 in (0.30 m) lateral displacements, shall be less than: Occupant Impact Velocity-fps Longitudinal: $40/F_1$ Lateral: $30/F_2$ and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations—g's Longitudinal: $20/F_3$ Lateral: $20/F_4$ where F_1, F_2, F_3, and F_4 are appropriate acceptance factors.
	G. (Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60 g, Head Injury Criteria of 1000, and femur force of 2250 lb (10 kN) and by FMVSS 214, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000, and occupant lateral impact velocity of 30 fps (9.1 m/s).
Vehicle Trajectory	H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.
	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 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.
	J. Vehicle trajectory behind the test article is acceptable.

Table 5. NCHRP Report 350 crash test matrix and impact conditions for features tested.

Test Level	Feature	Test Designation	Impact Conditions			Impact Point	Evaluation Criteria
			Vehicle	Speed (km/h)	Angle (deg)		
2	Longitudinal Barriers Length of Need (LON)	2-10	820C	70	20	Critical impact point	A,D,F,H,I,(J),K,M
		2-11	2000P	70	25	Critical impact point	A,D,F,K,L,M
	Longitudinal Barriers Transition	2-20	820C	70	20	Critical impact point	A,D,F,H,I,(J),K,M
		2-21	2000P	70	25	Critical impact point	A,D,F,K,L,M
	Gating Terminals	2-30	820C	70	0	Nose at quarter-point	C,D,F,H,I,(J),K,N
		2-31	2000P	70	0	Nose at centerline	C,D,F,H,I,(J),K,N
		2-32	820C	70	15	Nose	C,D,F,H,I,(J),K,N
		2-33	2000P	70	15	Nose	C,D,F,H,I,(J),K,N
		2-34	820C	70	15	Critical impact point	C,D,F,H,I,(J),K,N
		2-35	2000P	70	20	Beginning of LON	A,D,F,K,L,M
		2-39	2000P	70	20	L/2 reverse direction	C,D,F,K,L,M,N
	Support Structures	2-60	820C	35	0-20	Centerline	B,D,F,H,I,(J),K,N
		2-61	820C	70	0-20	Centerline	B,D,F,H,I,(J),K,N
3	Longitudinal Barriers Length of Need	3-10	820C	100	20	Critical impact point	A,D,F,H,I,(J),K,M
		3-11	2000P	100	25	Critical impact point	A,D,F,K,L,M
	Longitudinal Barriers Transition	3-20	820C	100	20	Critical impact point	A,D,F,H,I,(J),K,M
		3-21	2000P	100	25	Critical impact point	A,D,F,K,L,M
	Gating Terminals	3-30	820C	100	0	Nose at quarter-point	C,D,F,H,I,(J),K,N
		3-31	2000P	100	0	Nose at centerline	C,D,F,H,I,(J),K,N
		3-32	820C	100	15	Nose	C,D,F,H,I,(J),K,N
		3-33	2000P	100	15	Nose	C,D,F,H,I,(J),K,N
		3-34	820C	100	15	Critical impact point	C,D,F,H,I,(J),K,N
		3-35	2000P	100	20	Beginning of LON	A,D,F,K,L,M
		3-39	2000P	100	20	L/2 reverse direction	C,D,F,K,L,M,N
	Support Structures	3-60	820C	35	0-20	Centerline	B,D,F,H,I,(J),K,N
		3-61	820C	100	0-20	Centerline	B,D,F,H,I,(J),K,N

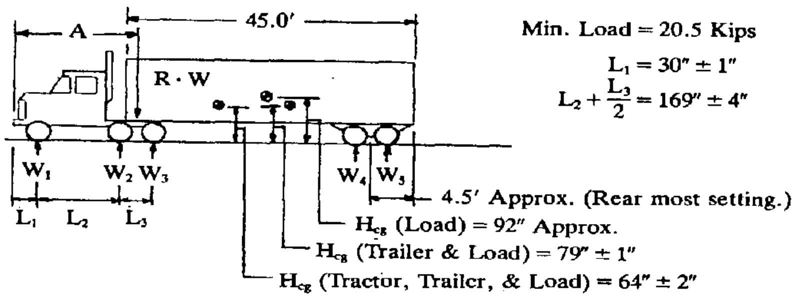
Table 6. Safety evaluation criteria for NCHRP Report 350.

<table>
<tr><th>Evaluation Factors</th><th>Evaluation Criteria</th></tr>
<tr><td rowspan="3">Structural Adequacy</td><td>A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td>B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.</td></tr>
<tr><td>C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.</td></tr>
<tr><td rowspan="7">Occupant Risk</td><td>D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td></tr>
<tr><td>E. Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.</td></tr>
<tr><td>G. It is preferable, although not essential, that the vehicle remain upright during and after collision.</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>9</td><td>12</td></tr>
<tr><td>Longitudinal</td><td>3</td><td>5</td></tr>
</table></td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ridedown Acceleration Limits (g's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td></tr>
</table></td></tr>
<tr><td>J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition).</td></tr>
<tr><td rowspan="4">Vehicle Trajectory</td><td>K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</td></tr>
<tr><td>L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.</td></tr>
<tr><td>M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

Table 7. 1989 AASHTO *Guide Specifications for Bridge Railings* crash test matrix and impact conditions.

		TEST SPEEDS - mi/h			
		TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
PERFORMANCE LEVELS		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 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	Required	a,b,c,d,g	a,b,c,d	a,b,c	a,b,c
	Desirable	e,f,h	e,f,g,h	d,e,f,h	d,e,f,h

Note 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.

Table 8. Safety evaluation criteria for 1989 AASHTO *Guide Specifications.*

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

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

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

Occupant Impact Velocity-fps	
Longitudinal	Lateral
30	25

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

Occupant Ridedown 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.

As shown in table 2, crash tests on the Michigan thrie-beam transition design, the guardrail system for low-fill culvert, the Pennsylvania transition design, the modified breakaway cable terminal (BCT) design, and the last three of the four tests on the mini-MELT for W-beam, weak-post (G2) guardrail system were performed and evaluated according to requirements set forth in NCHRP Report 230. The Washington, DC, PL-1 bridge rail crash testing was performed according to NCHRP Report 230 and evaluated to the 1989 AASHTO bridge rail guide. The single slope bridge rail and NETC PL-2 bridge rail crash tests were performed according to NCHRP Report 350 and evaluated to the 1989 AASHTO bridge rail guide. Crash testing on the existing guardrail systems, the MELT, the modified MELT, and the first test on the mini-MELT were performed and evaluated according to NCHRP Report 350.

2.2 CRASH TEST PROCEDURES

As mentioned previously, crash testing under this contract began in 1989 while NCHRP Report 230 was the standard guideline for crash testing. In 1993, FHWA adopted NCHRP Report 350 as the new guideline. Although the crash test matrix changed, the testing and data analysis procedures remained basically the same for both sets of guides and the 1989 AASHTO *Guide Specifications* with slight changes in reporting procedures. Brief descriptions of these procedures are presented as follows.

2.2.1 Electronic Instrumentation and Data Processing

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 (c.g.) 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. In addition, a biaxial accelerometer was placed in the front of the 8000 kg (17 636 lb) single-unit truck. The accelerometers were strain-gauge type with a linear millivolt output proportional to acceleration.

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

The multiplex of data channels, transmitted on one radio frequency, were received at the data acquisition station and demultiplexed into separate tracks of Inter-Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data were played back from the tape machines, filtered with an SAE J211 filter, and digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on 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 were plotted from the digitized data of the vehicle-mounted accelerometers using a commercially available software package (LOTUS 123). For reporting purposes under NCHRP Report 350, the data from the vehicle-mounted accelerometers were filtered with a 60-Hz digital filter and then plotted using Quattro Pro.

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.001-s intervals (NCHRP Report 230) or 0.00067-s intervals (NCHRP Report 350) and then instructed 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. In NCHRP Report 350 the coordinates changed to conform with Society of Automotive Engineers (SAE) standards; however, the respective coordinates for each test are shown on each plot.

2.2.2 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 820C (small passenger car) and the 2000P (pickup truck) test vehicle. The dummy was uninstrumented; however, a high-speed onboard camera recorded the motions of the dummy during the test. No dummy was used in the 8000S (single-unit truck) test vehicle.

2.2.3 Photographic Instrumentation and Data Processing

Photographic coverage of tests on longitudinal barriers, transitions, terminals, and bridge rails included four high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the terminal at an angle; a third placed to have a field of view parallel to and aligned with the terminal installation at the downstream end; and a fourth placed onboard the vehicle to record the motions of the dummy placed in the driver seat during the test sequence. For tests on support structures, two high-speed cameras were used: one perpendicular to the vehicle path/test article and one 45 degrees behind the test article. A flashbulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the rail and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a Betacam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

2.2.4 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 tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional 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. The system had a 2 to 1 speed ratio between the test and tow vehicle. Just prior to impact with the installation, the test vehicle was released to be freewheeling and unrestrained. The vehicle remained freewheeling (i.e., no steering or braking inputs) until it cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring it to a safe and controlled stop.

III. MICHIGAN THRIE-BEAM TRANSITION

The Michigan Department of Transportation has designed a thrie-beam transition for use in transitioning from a standard W-beam guardrail to a safety-shaped concrete parapet bridge rail. This chapter presents the details of a full-scale crash test and the performance of this transition design 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 NCHRP Report 230.

3.1 TEST INSTALLATION

A 2.44-m (8-ft) section of Michigan Type 5 (concrete safety-shaped) bridge railing was constructed and tied into an existing 864-mm (34-in) high, concrete safety-shaped median barrier. Approximately 22.9 m (75 ft) of approach guardrail was constructed, including a Detail T-4 guardrail to bridge rail transition section, one 3.81-m (12-ft, 6-in) section of standard Type T (thrie-beam) guardrail, one 1.91-m (6-ft, 3-in) transition section from thrie-beam to W-beam guardrail, and a 11.4-m (37-ft, 6-in) section of a Breakaway Cable Terminal (BCT) guardrail anchorage. The Detail T-4 guardrail to bridge rail transition consisted of one 3.81-m (12-ft, 6-in) section of thrie beam, one 1.91-m (6-ft, 3-in) transition from thrie-beam to W-beam, and a W-beam end section anchored to the concrete bridge railing, details of which are shown in figure 1. There was also a 5.18-m (17-ft) long curb and gutter section with backfill to the top of the curb in the transition area, details of which are shown in figure 2. Photographs of the completed Michigan thrie-beam transition system prior to the full-scale crash test are shown in figure 3.

3.2 TEST NUMBER 471470-1 (NCHRP REPORT 230 TEST DESIGNATION 30)

Test vehicle: 1979 Cadillac Coupe de Ville	Impact speed: 100.1 km/h (62.2 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 26.0 degrees
Gross static weight: 2118 kg (4666 lb)	

The vehicle impacted the transition approximately 2.9 m (9.4 ft) from the end of the concrete bridge railing. The vehicle slowly began to redirect and, as it continued forward, it began to deform at the A-pillar and then to redirect significantly. The vehicle began traveling parallel to the transition at 81.4 km/h (50.6 mi/h) and, almost immediately afterwards, the rear of the vehicle impacted the transition. The vehicle exited the transition traveling at 77.7 km/h (48.3 mi/h) with an exit trajectory of 14.1 degrees. The brakes were applied after the vehicle cleared the test installation and the vehicle came to rest 66 m (218 ft) down and 27 m (88 ft) in front of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 4.

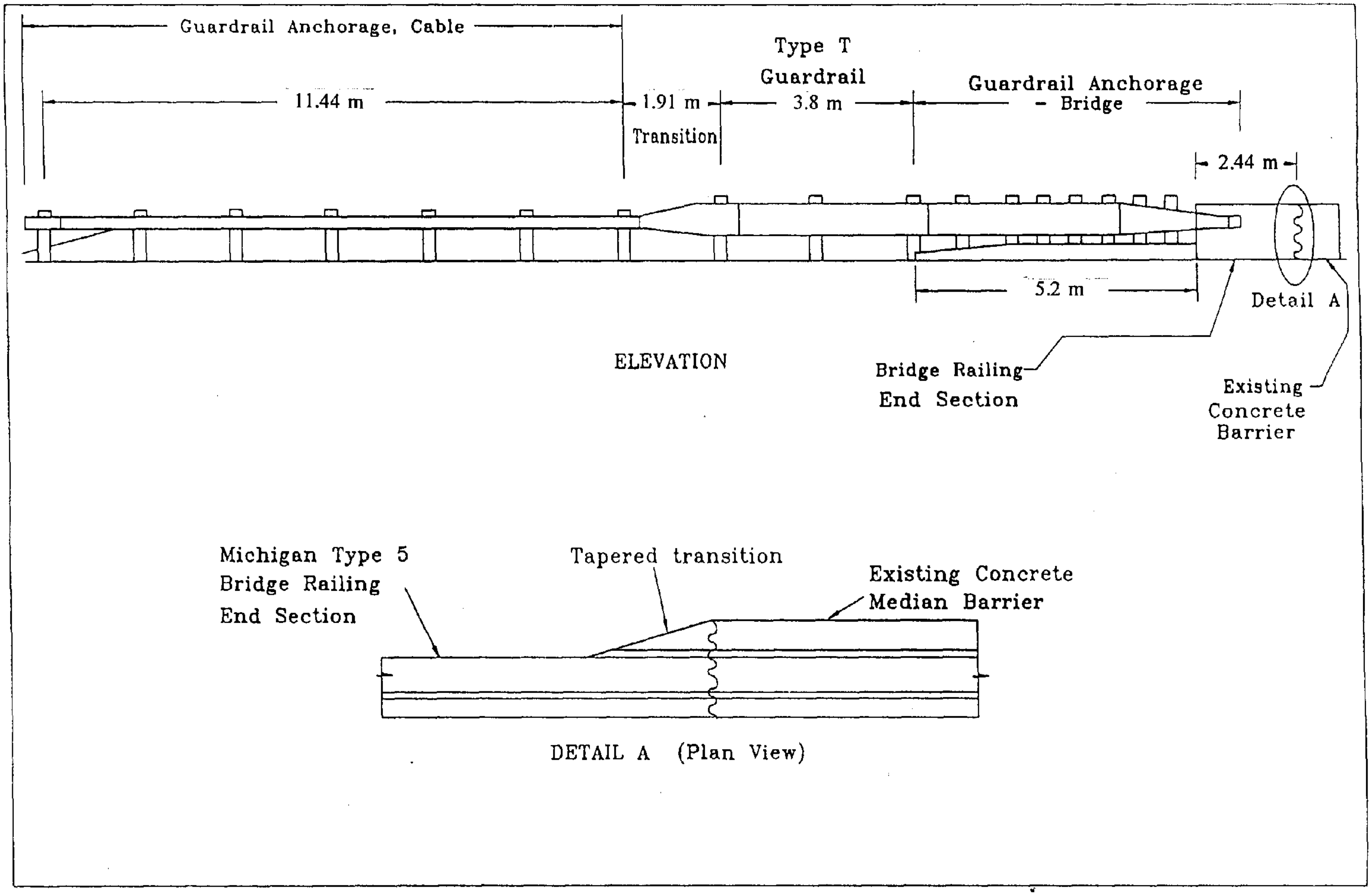


Figure 1. Details of Michigan transition system.

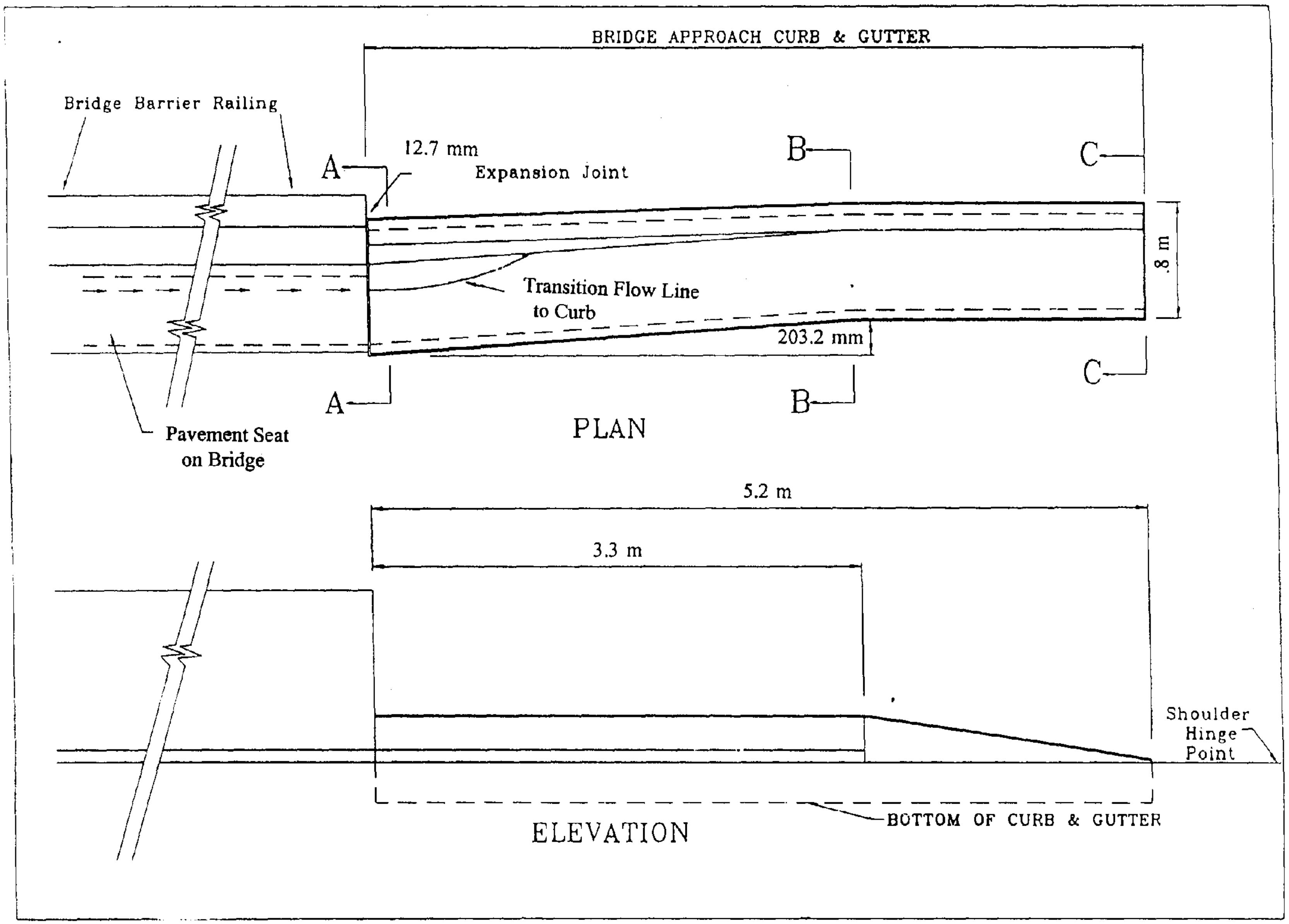


Figure 2. Details of approach curb and gutter section.

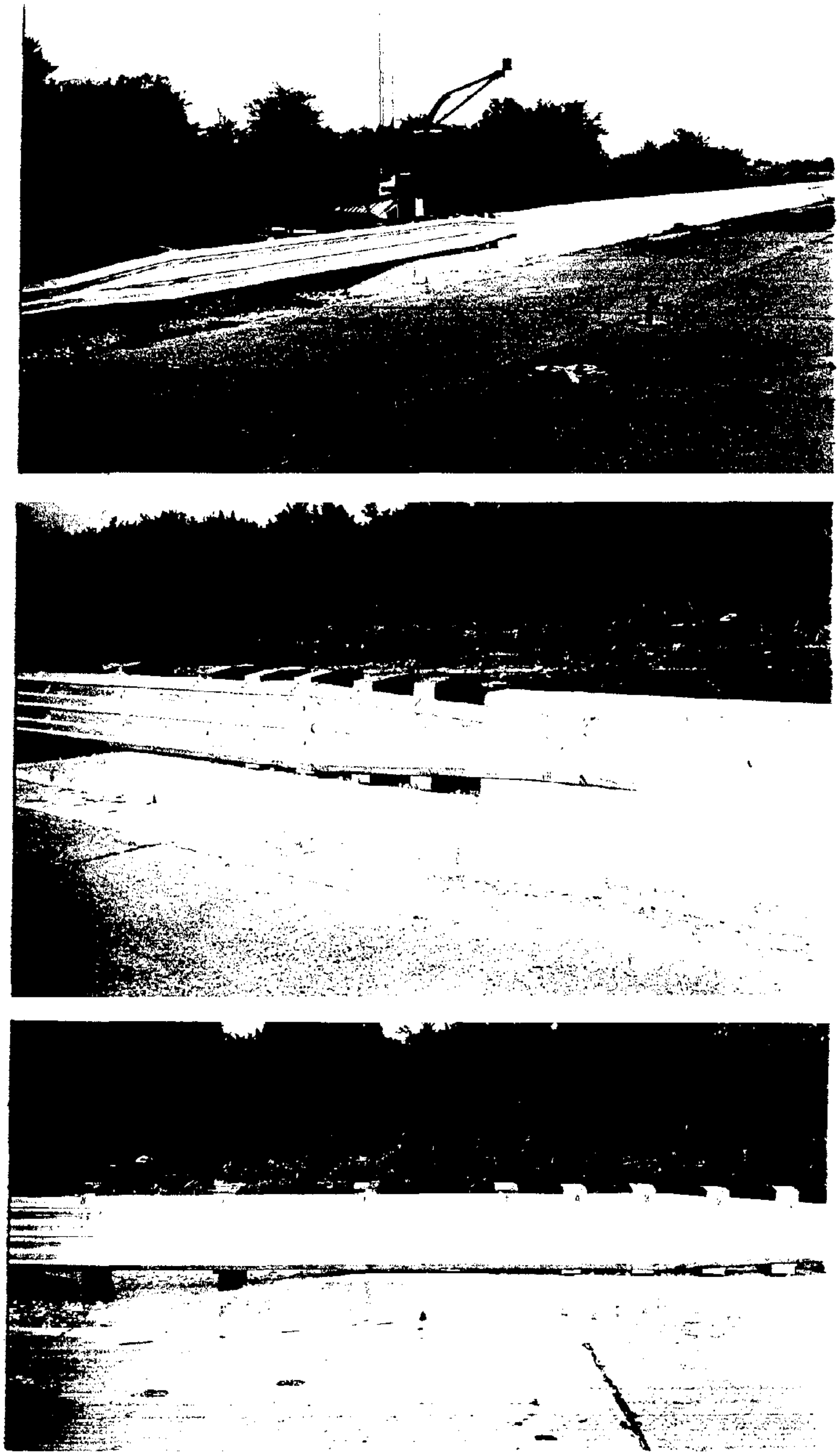
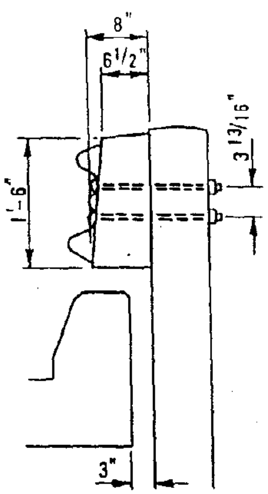


Figure 3. Photographs of Michigan thrie-beam transition prior to testing.

0.000 s | 0.092 s | 0.185 s | 0.277 s



Post 1

Test No.	7147-1	Impact Speed	100.1 km/h (62.2 mi/h)
Date	07/31/90	Impact Angle	26.0 deg
Test Installation	Michigan Transition with 12-Gauge Thrie Beam	Speed at Parallel	81.4 km/h (50.6 mi/h)
		Exit Speed	77.7 km/h (48.3 mi/h)
Installation Length	23 m (75 ft)	Exit Trajectory	14.1 deg
Max. Dynamic Deflection	Not Attainable	Vehicle Accelerations (Max. 0.050-s avg)	
Max. Perm. Deformation	0.1 m (0.3 ft)	Longitudinal	-7.5 g's
Test Vehicle	1979 Cadillac Coupe deVille	Lateral	-13.7 g's
Vehicle Weight		Occupant Impact Velocity	
Test Inertia	2043 kg (4500 lb)	Longitudinal	7.2 m/s (23.6 ft/s)
Gross Static	2118 kg (4666 lb)	Lateral	8.7 m/s (28.7 ft/s)
Vehicle Damage Classification		Occupant Ridedown Accelerations	
TAD	11FL6 & 11LD6	Longitudinal	-7.9 g's
CDC	11FLEK2 & 11LDES3	Lateral	-12.2 g's
Maximum Vehicle Crush	432 mm (17.0 in)		

Figure 4. Summary of results for test 471470-1.

The transition received moderate damage to the thrie beam. The curb was chipped and there were tire marks along the contact area. There was also some slight movement in the curb and gutter section. Total length of contact with the transition was 4.3 m (14 ft), and the maximum permanent deformation was 102 mm (4.0 in) at post 4.

The vehicle sustained severe damage to the left side. The tie rod was bent and the windshield and left door glass was broken. There was damage to the front bumper, hood, grill, radiator and fan, left front quarter panel, left door, left rear quarter panel, and the rear bumper. The left front wheel rim was split, the welds were broken, and the tire was cut. The left rear rim and tire were also damaged. Maximum crush to the vehicle was 432 mm (17.0 in) at the left front corner at bumper height.

3.3 SUMMARY OF FINDINGS

The Michigan thrie-beam transition system performed satisfactorily in the crash test, as shown in table 9. The vehicle was smoothly redirected and did not penetrate or go over the transition. 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. Some intrusion into the occupant compartment occurred with moderate deformation of the compartment. Vehicle trajectory at loss of contact indicates minimal intrusion into adjacent traffic lanes. The lateral occupant impact velocity of 8.7 m/s (28.7 ft/s) was below the limit of 9.1 m/s (30.0 ft/s), but higher than the design value of 6.1 m/s (20 ft/s), as outlined in NCHRP Report 230. Otherwise, the longitudinal occupant impact velocity and the highest 0.010-s average ridedown accelerations for both the longitudinal and lateral directions are below the design values. The velocity change of 22.4 km/h (13.9 mi/h) was less than the recommended velocity change of 24.1 km/h (15 mi/h), and the exit angle of 14.1 degrees was less than 60 percent of the impact angle.

In summary, the Michigan thrie-beam transition system is judged to have met all evaluation criteria set forth in NCHRP Report 230.

Table 9. Assessment of results of test 471470-1 (according to NCHRP 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-1 | Test Date: 07/31/90

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 did not penetrate or go over the barrier and was smoothly redirected.	Pass
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 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 no deformation or intrusion into the passenger compartment.	Pass
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 = 7.2 m/s (23.6 ft/s) Lateral Impact Velocity = 8.7 m/s (28.7 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 = -7.9 g's Lateral Occupant Ridedown = -12.2 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 66 m (218 ft) downstream and 27 m (88 ft) in front of the point of impact, indicating minimal intrusion.	Pass
I. In test 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 22.4 km/h (13.9 mi/h) (<24.1 km/h (15 mi/h); exit angle 14.1 degrees (<15.6 degrees or 60 percent of 26.0 degrees)	Pass

IV. GUARDRAIL SYSTEM OVER LOW-FILL CULVERT

A problem arises when a roadside guardrail needs to continue across a low-fill box culvert. Full embedment of the guardrail post(s) is not possible over the box culvert because of the shallow soil cover. Previous crash testing has demonstrated that posts with short embedment depths could be pulled out from the ground and subsequently fall into the path of the vehicle's tires. The resulting tire-post forces could then cause snagging and/or vaulting of the vehicle. For a steel-post guardrail system, one design that has been successfully crash tested is to bolt the short post(s) to the top of the box culvert.[4] However, this solution is not applicable to wood-post guardrail systems without switching from wood to steel posts for the segment over the low-fill box culvert. Also, this requires specially fabricated steel posts and increased installation costs.

A computer simulation study was first conducted to evaluate alternate designs for use with wood-post guardrail systems over low-fill box culverts. The results of the simulation study suggested that a long-span nested W-beam rail with no posts over the culvert would be the best design among the alternatives evaluated.[5] A span length of 3.81 m (12 ft, 6 in) in conjunction of a minimum length of 7.62 m (25 ft) of nested W-beam rail was first crash tested (test no. 471470-2) with successful results. In fact, the system performed so well that it was decided to increase the span length to 5.72 m (18 ft, 9 in) with the minimum length of the nested W-beam rail increased to 11.43 m (37 ft, 6 in). A W-beam rail section was added to the rear of the system overlapping the long span to provide added strength.

A second crash test (test no. 471470-4) was conducted on this 5.72-m (18 ft, 9 in) long-span nested W-beam guardrail system with a W-beam rail section to the rear of the system, and the results indicated that this system also performed very well. The good performance of the system in the crash test indicated that the system would likely work without the W-beam rail section on the rear of the guardrail. A third crash test (test no. 471470-5) was then conducted on this 5.72-m (18-ft, 9-in) long-span nested W-beam guardrail system without the W-beam rail section on the rear of the guardrail, also with successful results.

This chapter presents the results and evaluation of impact performance on these three crash tests, one for each of the three designs of the guardrail system for low-fill culvert. All three crash tests involved a 2043-kg (4500 lb) passenger car impacting the guardrail 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 NCHRP Report 230.

4.1 TEST INSTALLATION

A 45.7-m- (150-ft-) long test installation was constructed for this test, including 26.7 m (87.5 feet) of standard strong-post, blocked-out, W-beam wood post (G4(2W)) guardrail for the length-of-need section, a 7.6-m (25-ft) turned down end anchorage on the downstream end, and a 11.4-m (37-ft, 6-in) breakaway cable terminal (BCT) anchorage on the upstream end. The standard guardrail installation included 152-mm × 203-mm × 1.82-m (6-in × 8-in × 6-ft) wood posts with 152-mm × 203-mm × 256-mm (6-in × 8-in × 14-in) wood blockouts, spaced 1.91 m (6 ft, 3 in) center to center. The W-beam rail sections are made of 12-gauge galvanized steel, 3.81 m (12 ft, 6 in) in length.

For the first test (test no. 471470-2), a 3.81-m (12-ft, 6-in) span was constructed in the center of the test installation to simulate the long span over a low-fill box culvert, as shown in figure 5. The minimum length of 7.62 m (25 ft) of nested W-beam rail was used, which allowed for nested rail over the culvert and one post span on either side of the culvert. Since only 3.8-m (12-ft, 6-in) W-beam rail elements were used, the 7.62 m (25 ft) of nested rail resulted in a splice in the middle of the long span rather than at a post.The completed test installation is shown in figure 5. Photographs of the test installation are shown in figure 6.

For the second test (test no. 471470-4), a 5.72-m (18-ft, 9-in) span was constructed in the center of the test installation, as shown in figure 7. Three 3.81-m (12-ft, 6-in) sections of nested W-beam were used for a total length of 11.43 m (37 ft, 6 in). Two 3.81-m (12-ft, 6-in) sections of W-beam rails were added to the rear of the guardrail, extending over the culvert span. Photographs of this completed test installation are shown in figure 8. For the third test (test no. 471470-5), the test installation was similar to that in the second test but without the W-beam rail section on the rear of the guardrail, as shown in figure 9. Photographs of the completed test installation are shown in figure 10.

4.2 TEST NUMBER 471470-2 (NCHRP REPORT 230 TEST DESIGNATION 10)

Test vehicle: 1981 Cadillac Fleetwood	Impact speed: 100.9 km/h (62.7 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.5 degrees
Gross static weight: 2120 kg (4669 lb)	

The vehicle impacted the guardrail system approximately 305 mm (1 ft) downstream of post 12 (upstream post for the 3.81-m (12-ft, 6-in) long span over the simulated culvert). The impact point was selected to provide maximum deflection at the downstream post of the long span (post 13), based on results from the computer simulation study. Shortly after impact, the vehicle began to redirect. As the vehicle continued forward, a slight pocket was formed at post 13. The right front tire of the vehicle contacted post 13, resulting in both front tires being turned abruptly to the right. The rear of the vehicle contacted the guardrail and the vehicle was traveling parallel to the guardrail system at 79.5 km/h (49.4 mi/h). The right front tire contacted post 14. Maximum dynamic deflection of the guardrail was 0.9 m (3.1 ft). The vehicle exited the guardrail traveling at 67.9 km/h (42.2 mi/h) with an exit trajectory of 11.0 degrees. The brakes were applied after the vehicle cleared the test installation. The vehicle rotated clockwise 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. The front of the vehicle then impacted the end of another concrete barrier. The vehicle came to rest next to the concrete barrier section, 53 m (173 ft) downstream from the point of initial

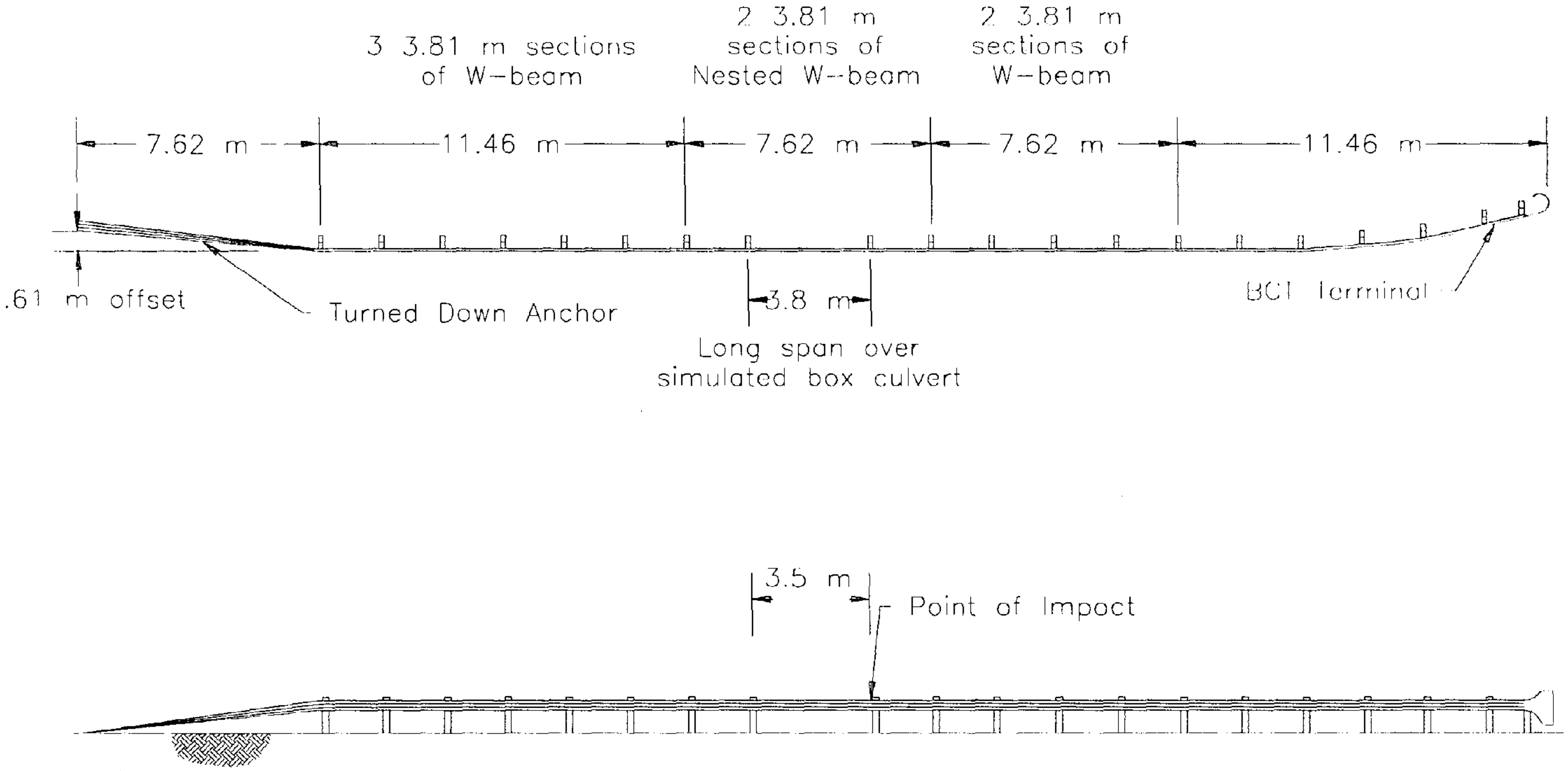


Figure 5. Nested long span W-beam installation for test 471470-2.

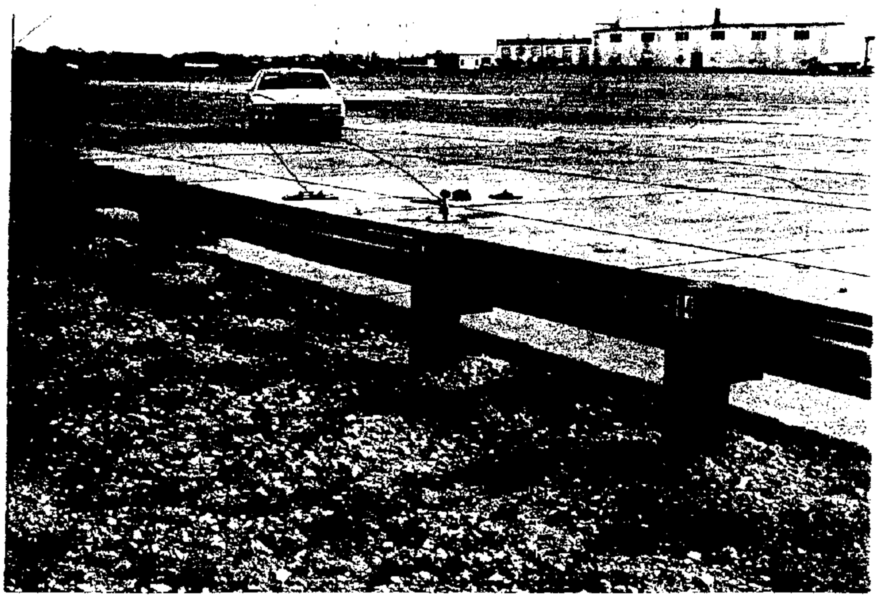


Figure 6. Photographs of test installation 471470-2.

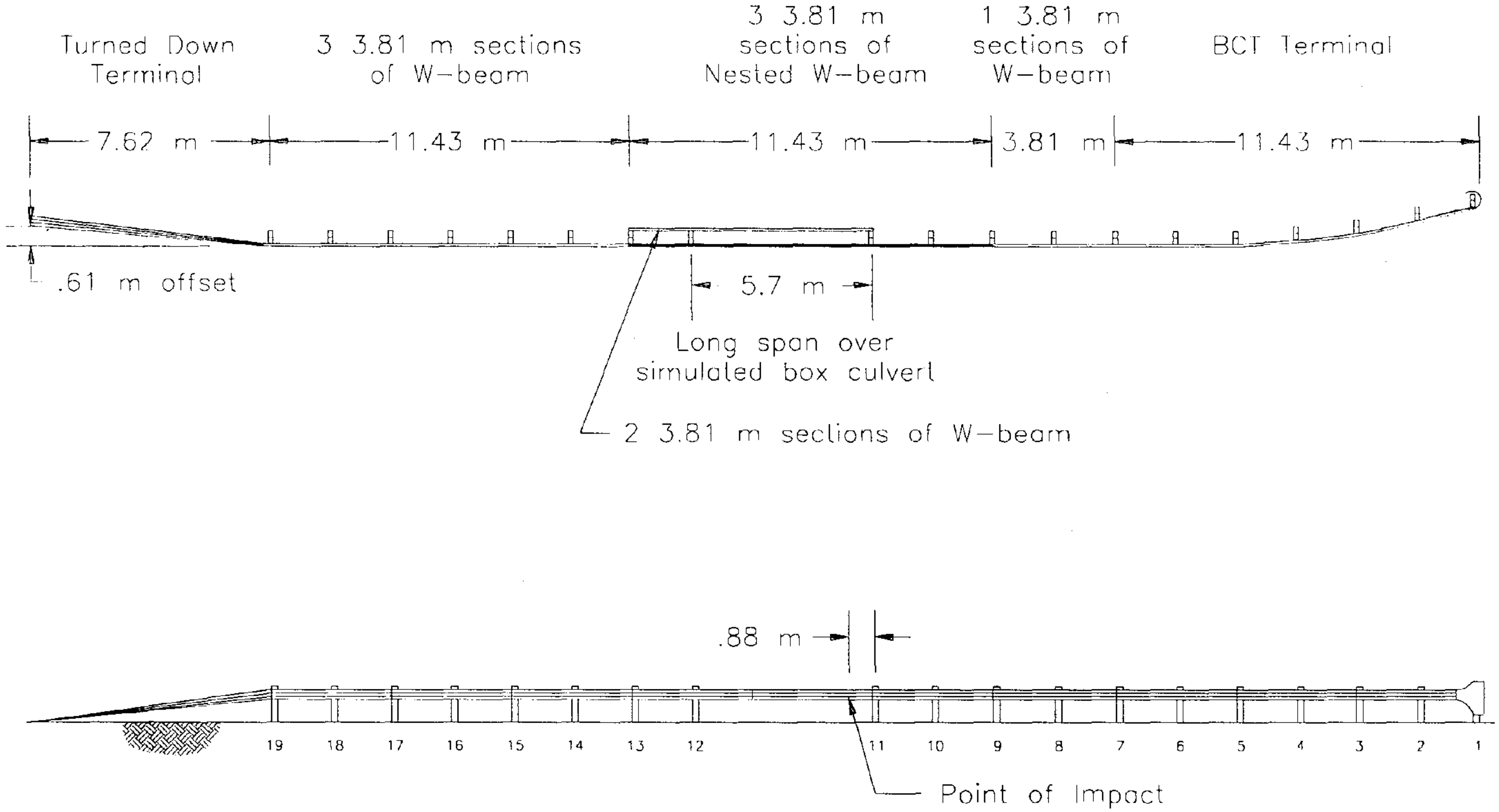
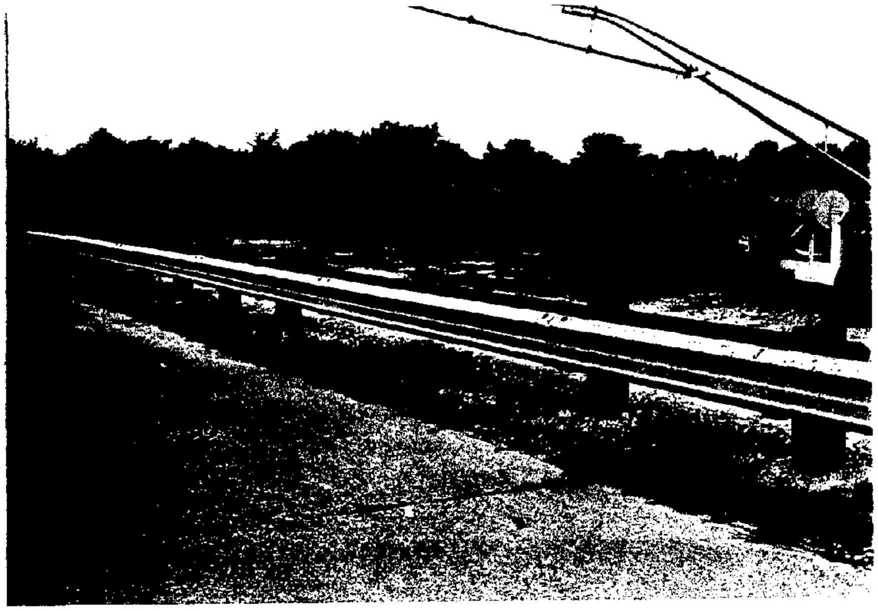


Figure 7. Nested long span W-beam installation for test 471470-4.



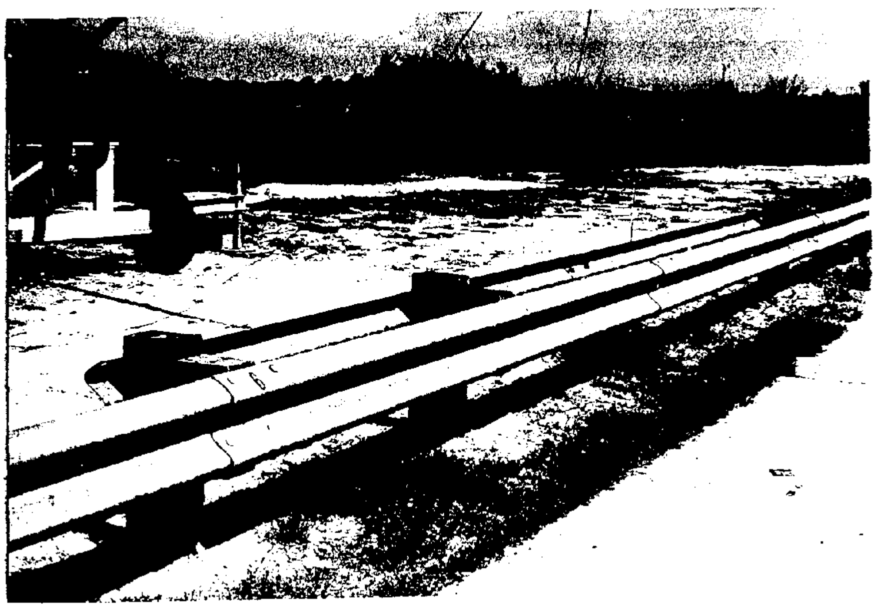


Figure 8. Photographs of 471470-4 test installation.

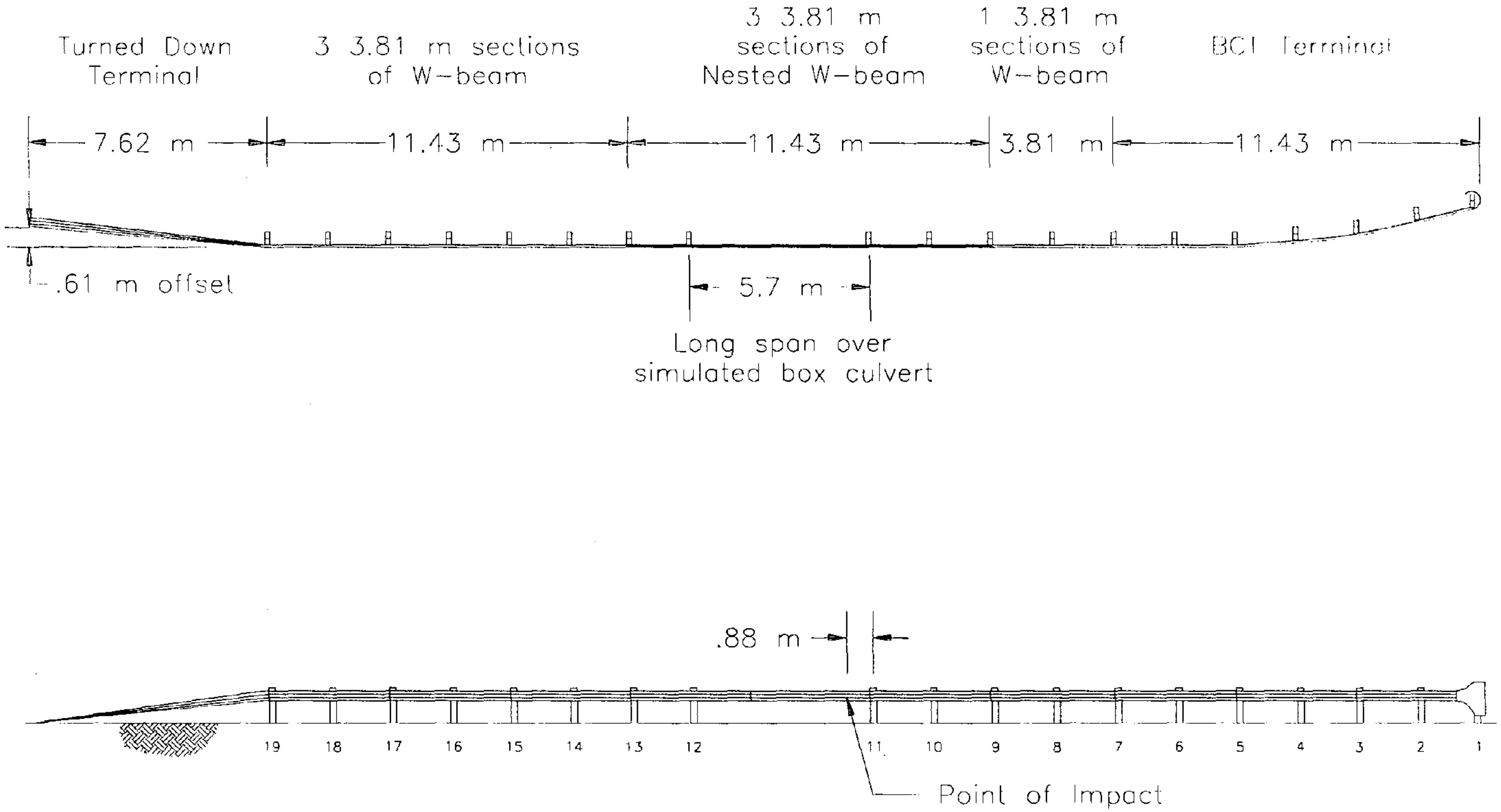
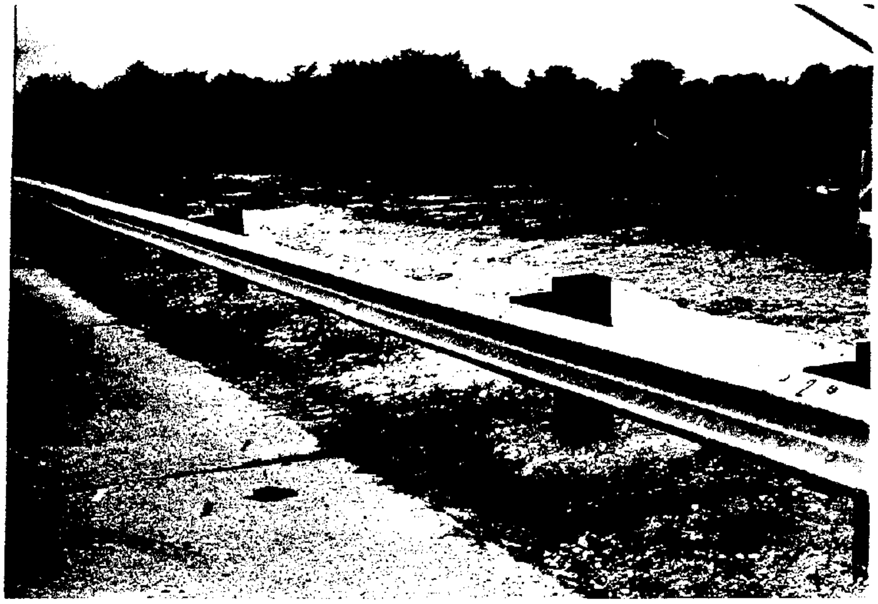


Figure 9. Nested long span W-beam installation for test 471470-5.



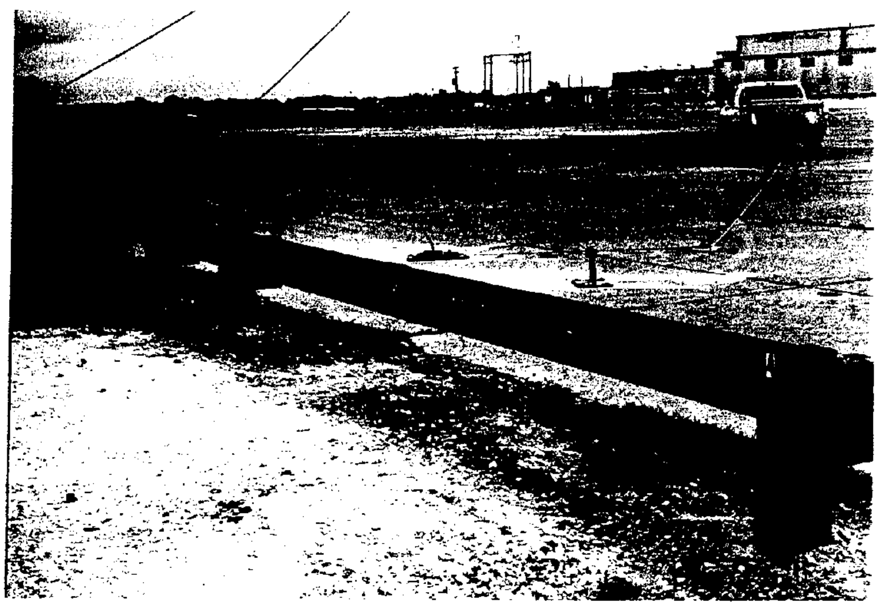


Figure 10. Photographs of test installation 471470-5.

impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 11.

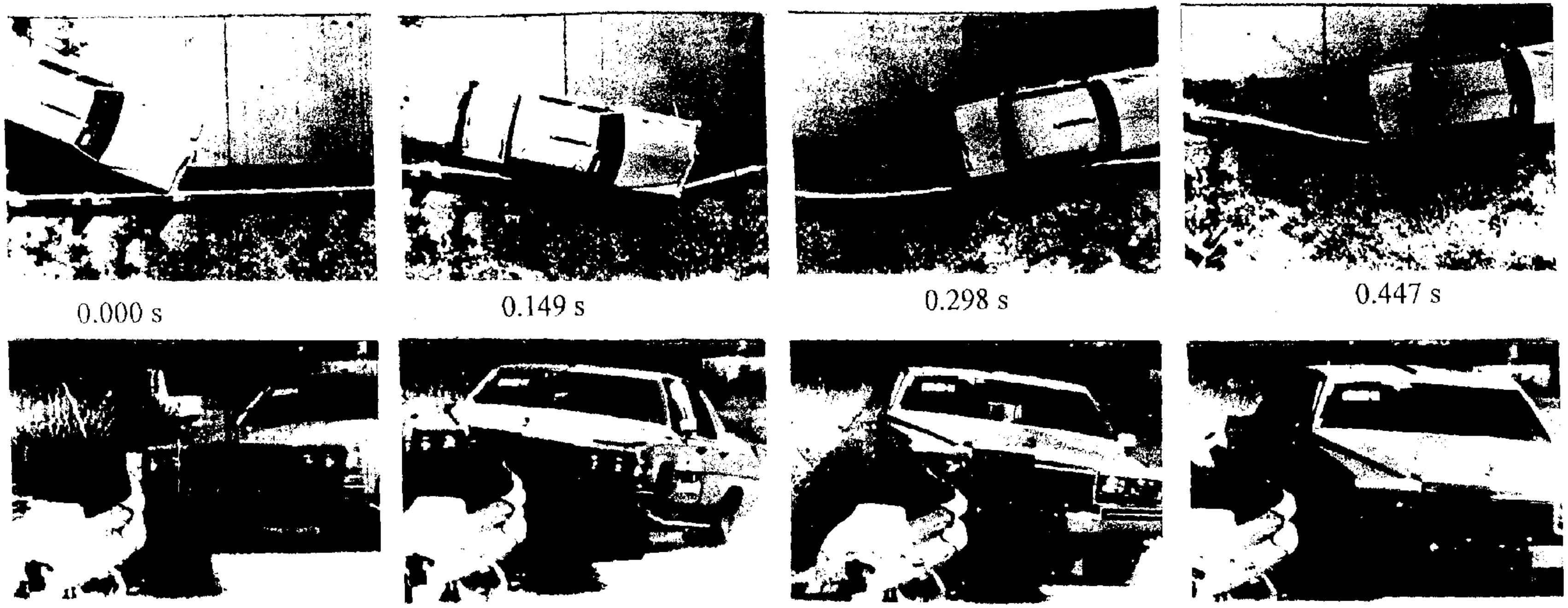
The total length of contact of the vehicle with the guardrail system was 7.2 m (23.5 ft). The maximum permanent deformation of the W-beam rail element was 0.7 m (2.4 ft), located approximately 0.92 m (3 ft) upstream of post 13 (the downstream post of the long span). There was some flattening of the W-beam rail element at the lower corrugation upstream of post 13 as the vehicle pocketed slightly at the post and pressed the W-beam rail element against the blockout and the post. Post 13 was pushed back 324 mm (12.75 in) at ground level and 714 mm (28.5 in) at the center of the W-beam rail element. The blockout at post 13 was broken and separated from the post and the head of bolt attaching the rail to the blockout and post was pulled through the nested W-beam rail elements. There were also slight movements at the two end anchors.

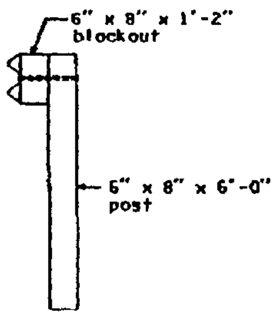
The vehicle's tie rod was bent and the windshield was broken. There was damage to the front bumper, hood, grill, radiator and fan, right front quarter panel, right front and rear doors, right rear quarter panel, and the rear bumper. The wheelbase on the right side was shortened from 3086 mm (121.5 in) to 2946 mm (116.0 in). The right front and rear rims and tires were damaged from contact with the posts. Maximum crush to the vehicle was 330 mm (13.0 in) at the right front corner at bumper height. Note that much of the damage to the front of the vehicle was the result of the vehicle impacting the end of another concrete barrier near the end of the vehicle trajectory.

4.3 TEST NUMBER 471470-4 (NCHRP REPORT 230 TEST DESIGNATION 10)

Test vehicle: 1979 Cadillac Sedan deVille	Impact speed: 90.4 km/h (56.2 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.0 degrees
Gross static weight: 2120 kg (4670 lb)	

The vehicle impacted the guardrail system approximately 0.9 m (2.9 ft) downstream of post 11 (upstream post for the 5.72-m (18-ft, 9-in) long span over the simulated culvert). The impact point was selected to provide maximum deflection at the downstream post (post 12) of the long span, based on results from the computer simulation study. Shortly after initial impact, the vehicle began to redirect and contact was made with the W-beam on the rear of the post. The right front tire of the vehicle contacted post 12, resulting in both front tires being turned abruptly to the right. The rear of the vehicle contacted the guardrail and the vehicle was traveling parallel to the guardrail system at 71.9 km/h (44.7 mi/h). Maximum dynamic deflection of the guardrail was 0.9 m (3.1 ft) to the front rail, and 0.64 m (2.1 ft) to the rear rail. The vehicle exited the guardrail traveling at 69.8 km/h (43.4 mi/h) with an exit trajectory of 12.3 degrees. The brakes were applied after the vehicle cleared the test installation. The vehicle rotated clockwise 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. The front of the vehicle impacted another guardrail installation. The vehicle then slid off the end of the other barrier and came to rest 119 m (390 ft) downstream





Section B-B

Test No.	7147-2
Date	09/25/90
Test Installation	Washington Nested W-beam with Wood Posts
Installation Length	46 m (150 ft)
Max. Dynamic Deflection	0.9 m (3.1 ft)
Max. Perm. Deformation	0.7 m (2.4 ft)
Test Vehicle	1981 Cadillac Fleetwood
Vehicle Weight	
Test Inertia	2043 kg (4500 lb)
Gross Static	2120 kg (4669 lb)
Vehicle Damage Classification	
TAD	01FR5 & 01RD4
CDC	01FREK2 & 01RDEW3
Maximum Vehicle Crush	330 mm (13.0 in)

Impact Speed	100.9 km/h (62.7 mi/h)
Impact Angle	24.5 deg
Speed at Parallel	79.5 km/h (49.4 mi/h)
Exit Speed	67.9 km/h (42.2 mi/h)
Exit Trajectory	11.0 deg
Vehicle Accelerations (Max. 0.050-s avg)	
Longitudinal	-4.5 g's
Lateral	7.1 g's
Occupant Impact Velocity	
Longitudinal	5.4 m/s (17.8 ft/s)
Lateral	4.8 m/s (15.9 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-6.5 g's
Lateral	12.9 g's

Figure 11. Summary of results for test 471470-2.

and 15 m (50 ft) behind the point of initial impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 12.

The maximum permanent deformation of the W-beam rail element was 0.7 m (2.3 ft), located approximately in the center of the long span. The rear rail element received a maximum permanent deflection of 0.54 m (21.25 in) at post 12. Post 12 was pushed back 279 mm (11.0 in) at ground level and 0.51 m (20.25 in) at the center of the W-beam rail element. The blockout at post 11 was twisted and the head of the bolt attaching the rail to the blockout and post was pulled through the nested W-beam rail elements. There was no movement at the two end anchors.

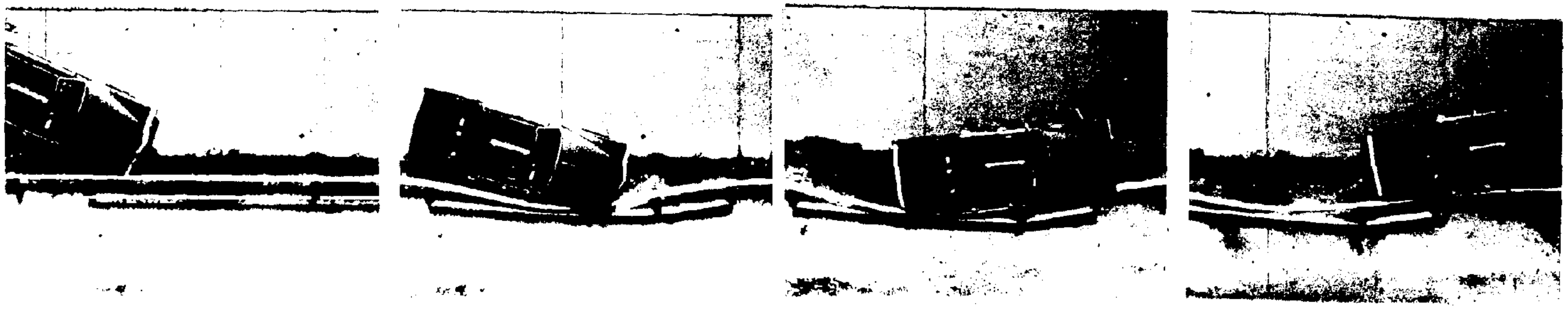
The vehicle's tie rod and lower control arm on the right side were damaged. There was damage to the front bumper, hood, grill, right front quarter panel, right front and rear doors, right rear quarter panel, and the rear bumper. The wheelbase on the right side was shortened from 3.07 m (121.0 in) to 3.06 m (120.5 in). The right front tire and rim was damaged from contact with the posts. Maximum crush to the vehicle was 229 mm (9.0 in) at the right front corner at bumper height. Note that much of the damage to the side of the vehicle was the result of the vehicle impacting another guardrail near the end of the vehicle trajectory.

4.4 TEST NUMBER 471470-5 (NCHRP REPORT 230 TEST DESIGNATION 10)

Test vehicle: 1982 Oldsmobile Regency 98	Impact speed: 98.0 km/h (60.9 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 25.1 degrees
Gross static weight: 2120 kg (4670 lb)	

The vehicle impacted the guardrail system approximately 0.9 m (2.9 ft) downstream of post 11 (upstream post for the 5.72-m (18-ft, 9-in) long span over the simulated culvert). The impact point was selected to provide maximum deflection at the downstream post (post 12) of the long span, based on results from the computer simulation study. Shortly after initial impact, the vehicle began to redirect. The right front tire of the vehicle contacted post 12 resulting in both front tires being turned abruptly to the right. The vehicle was traveling parallel to the guardrail system at 78.2 km/h (48.6 mi/h). Maximum dynamic deflection of the guardrail was 1.0 m (3.2 ft) to the front rail. The vehicle exited the guardrail traveling at 71.1 km/h (44.2 mi/h) with an exit trajectory of 10.4 degrees. The brakes were applied after the vehicle cleared the test installation. The vehicle rotated slightly clockwise 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. The vehicle came to rest 86.9 m (285 ft) downstream from the point of initial impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 13.

The maximum permanent deformation of the W-beam rail element was 0.8 m (2.5 ft), located approximately in the center of the long span. Post 12 was pushed back 419 mm (16.5 in) at ground level and 584 mm (23.0 in) at the center of the W-beam rail element. The



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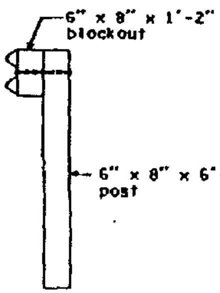
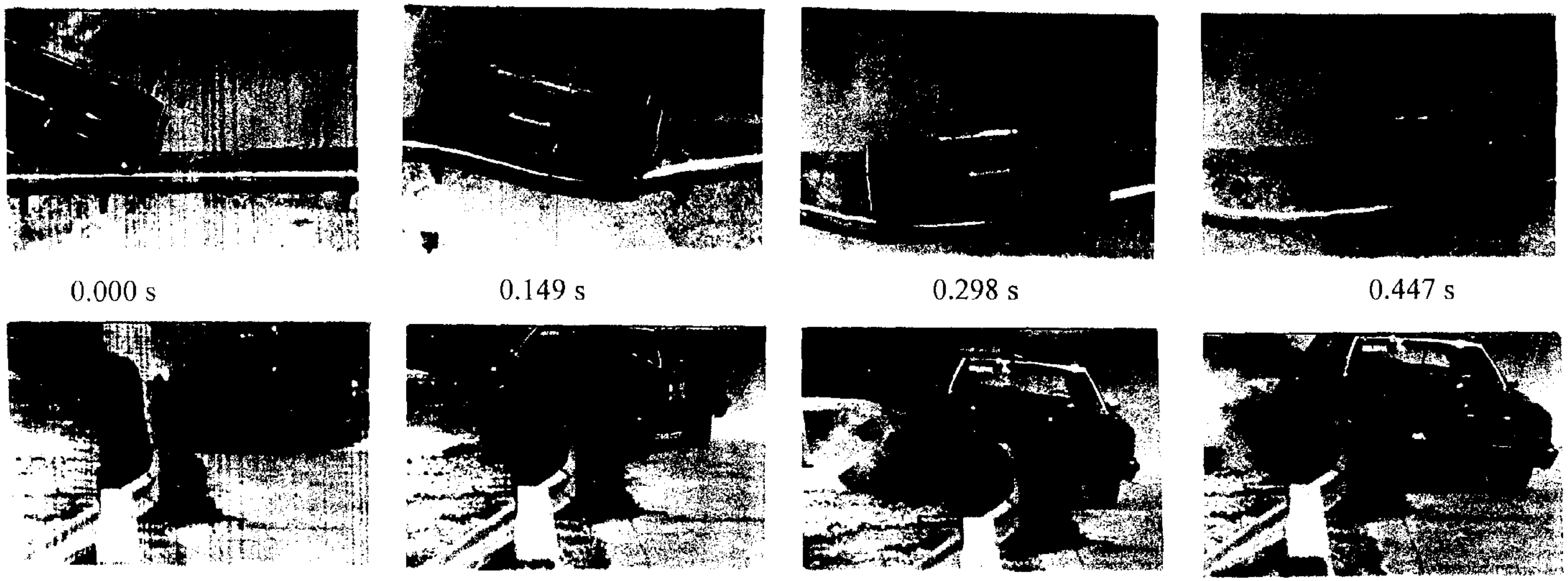
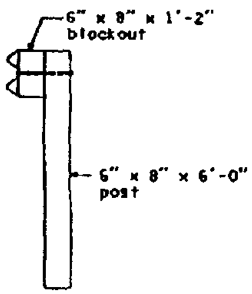


Section B-B

Test No.	7147-4	Impact Speed	90.4 km/h (56.2 mi/h)
Date	05/28/91	Impact Angle	24.0 deg
Test Installation	Washington Nested W-beam with Wood Posts	Speed at Parallel	71.9 km/h (44.7 mi/h)
		Exit Speed	69.8 km/h (43.4 mi/h)
Installation Length	46 m (150 ft)	Exit Trajectory	12.3 deg
Max. Dynamic Deflection	0.9 m (3.1 ft)	Vehicle Accelerations	
Max. Perm. Deformation	0.7 m (2.3 ft)	(Max. 0.050-s avg)	
Test Vehicle	1979 Cadillac Sedan deVille	Longitudinal	-2.7 g's
Vehicle Weight		Lateral	7.1 g's
Test Inertia	2043 kg (4500 lb)	Occupant Impact Velocity	
Gross Static	2120 kg (4670 lb)	Longitudinal	4.5 m/s (14.8 ft/s)
Vehicle Damage Classification		Lateral	4.5 m/s (14.7 ft/s)
TAD	01FR4 & 01RD3	Occupant Ridedown Accelerations	
CDC	01FREK2 & 01RDEW2	Longitudinal	-2.8 g's
Maximum Vehicle Crush	229 mm (9.0 in)	Lateral	9.0 g's

Figure 12. Summary of results for test 471470-4.





Section B-B

Test No.	7147-5	Impact Speed	98.0 km/h (60.9 mi/h)
Date	05/30/91	Impact Angle	25.1 deg
Test Installation	Washington Nested	Speed at Parallel	78.2 km/h (48.6 mi/h)
	W-beam with Wood Posts	Exit Speed	71.1 km/h (44.2 mi/h)
Installation Length	46 m (150 ft)	Exit Trajectory	10.4 deg
Max. Dynamic Deflection	1.0 m (3.2 ft)	Vehicle Accelerations	
Max. Perm. Deformation	0.8 m (2.5 ft)	(Max. 0.050-s avg)	
Test Vehicle	1982 Oldsmobile Rgency 98	Longitudinal	-2.7 g's
Vehicle Weight		Lateral	6.8 g's
Test Inertia	2043 kg (4500 lb)	Occupant Impact Velocity	
Gross Static	2120 kg (4670 lb)	Longitudinal	4.5 m/s (14.7 ft/s)
Vehicle Damage Classification		Lateral	4.3 m/s (14.2 ft/s)
TAD	01FR4 & 01RD3	Occupant Ridedown Accelerations	
CDC	01FREK2 & 01RDEW2	Longitudinal	-3.5 g's
Maximum Vehicle Crush	203 mm (8.0 in)	Lateral	9.7 g's

Figure 13. Summary of results for test 471470-5.

blockout at post 11 was separated from the post and rail elements and the post was split. There was no movement at the two end anchors.

The vehicle's upper control arm on the right side was damaged. There was damage to the front bumper, hood, grill, right front quarter panel, right front and rear doors, right rear quarter panel, and the rear bumper. The wheelbase on the right side was shortened from 3.02 m (119.0 in) to 2.97 m (117.0 in). The right front and rear tires and rims were damaged from contact with the posts. Maximum crush to the vehicle was 203 mm (8.0 in) at the right front corner at bumper height.

4.5 SUMMARY OF FINDINGS

Three long-span, nested W-beam guardrail designs for use over culverts were crash tested and evaluated, including:

1. A 3.81-m (12-ft, 6-in) span nested W-beam guardrail design (test no. 471470-2),

2. A 5.72-m (18-ft, 9-in) span nested W-beam guardrail design with a W-beam rail section in rear of guardrail (test no. 471470-4), and

3. A 5.72-m (18-ft, 9-in) span nested W-beam guardrail design without a W-beam rail section in rear of guardrail (test no. 471470-5).

The 3.81-m (12-ft, 6-in) long-span nested W-beam guardrail design performed very well in test 471470-2, as shown in the performance evaluation summary in table 10. The vehicle was smoothly redirected and did not penetrate or go over the guardrail system. 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 guardrail and after exiting the test installation. There was some intrusion into the occupant compartment, but essentially no deformation of the compartment. Vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

The occupant impact velocities and ridedown accelerations for both the longitudinal and the lateral directions were well below the desirable values outlined in NCHRP Report 230 guidelines. There was some slight pocketing and tire contact at the downstream post of the long span, but their effects were very minor and did not significantly affect the vehicle kinematics or trajectory. The velocity change of 33.0 km/h (20.5 mi/h) was higher than the recommended limit of 24.1 km/h (15 mi/h) according to NCHRP Report 230 guidelines. However, the exit angle of 11.0 degrees was considerably less than 60 percent of the impact angle.

Table 10. Assessment of results of test 471470-2 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-2 | Test Date: 09/25/90

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 did not penetrate or go over the barrier and was smoothly redirected.	Pass
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 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 essentially no deformation or intrusion into the passenger compartment.	Pass
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 = 5.4 m/s (17.8 ft/s) Lateral Impact Velocity = 4.8 m/s (15.9 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 = -6.5 g's Lateral Occupant Ridedown = 12.9 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 53 m (173 ft) downstream and aligned with the point of impact.	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 33.0 km/h (20.5 mi/h) (>24.1 km/h (15 mi/h); exit angle 11.0 degrees (<14.7 degrees or 60 percent of 24.5 degrees)	Marginal

One suggested improvement is to increase the length of the nested rail from the minimum of 7.62 m (25 ft) to 11.43 m (37 ft, 6 in) and add a W-beam rail section to the rear of the system to overlap the long span and provide added strength. This suggested change would not affect the impact performance of the system to any degree, but would eliminate the need to have a splice in the middle of the long span, which could be mistaken as a missing post.

The 5.72-m (18-ft, 9-in) long-span nested W-beam guardrail system with a W-beam rail section at the rear of the guardrail performed very well in crash test 471470-4, as shown in the performance evaluation summary in table 11. The vehicle was smoothly redirected and did not penetrate or go over the guardrail system. 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 guardrail and after exiting the test installation. There was no intrusion into the occupant compartment, and no deformation of the compartment. Vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

The occupant impact velocities and ridedown accelerations for both the longitudinal and the lateral directions were well below the desirable values outlined in NCHRP Report 230 guidelines. There was some slight pocketing and tire contact at the downstream post of the long span, but their effects were very minor and did not significantly affect the vehicle kinematics or trajectory. The velocity change and exit angle were within the recommended limit according to NCHRP Report 230 guidelines.

It should be noted that the actual impact speed of 90.4 km/h (56.2 mi/h) and impact angle of 24 degrees were considerably lower than the target impact speed of 96.5 km/h (60 mi/h) and impact angle of 25 degrees. However, the guardrail system performed so well in the crash test that there is little question that the guardrail system would have performed satisfactorily with the nominal impact conditions.

The 5.72-m (18-ft, 9-in) long-span nested W-beam guardrail system without the rear W-beam rail element also performed very well in test 471470-5, as shown in the performance evaluation summary in table 12. The vehicle was smoothly redirected and did not penetrate or go over the guardrail system. 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 guardrail and after exiting the test installation. There was no intrusion into the occupant compartment, and no deformation of the compartment. Vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

The occupant impact velocities and ridedown accelerations for both the longitudinal and the lateral directions were well below the desirable values outlined in NCHRP Report 230 guidelines. There was some slight pocketing and tire contact at the downstream post of the long span, but their effects were very minor and did not significantly affect the vehicle kinematics or trajectory. The velocity change was slightly higher than the recommended limit

Table 11. Assessment of results of test 471470-4 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-4 | Test Date: 05/28/91

<table>
<tr><th colspan="3">Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="3"><u>Structural Adequacy</u>
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.</td><td>The vehicle did not penetrate or go over the barrier and was smoothly redirected.</td><td>Pass</td></tr>
<tr><td colspan="3">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.</td><td>No debris showed potential for penetrating passenger compartment or presenting undue hazard to other traffic.</td><td>Pass</td></tr>
<tr><td colspan="3"><u>Occupant Risk</u>
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.</td><td>Vehicle remained upright and stable during collision. There was no deformation or intrusion into the passenger compartment.</td><td>Pass</td></tr>
<tr><td colspan="3">F. Impact velocity of hypothetical front seat passenger against the vehicle interior shall be less than</td><td rowspan="4">Longitudinal Impact Velocity = 4.5 m/s (14.8 ft/s)
Lateral Impact Velocity = 4.5 m/s (14.6 ft/s)</td><td rowspan="4">N/A</td></tr>
<tr><td></td><td colspan="2">Occupant Impact Velocity Limits (m/s)</td></tr>
<tr><td></td><td>Longitudinal</td><td>Lateral</td></tr>
<tr><td></td><td>12.2 (40 ft/s)</td><td>9.1 (30 ft/s)</td></tr>
<tr><td colspan="3">and vehicle highest 10-ms average accelerations subsequent to instant of hypothetical passenger contact should be less than:</td><td rowspan="4">Longitudinal Occupant Ridedown = -2.8 g's
Lateral Occupant Ridedown = 9.0 g's</td><td rowspan="4">N/A</td></tr>
<tr><td></td><td colspan="2">Occupant Ridedown Acceleration Limits (g's)</td></tr>
<tr><td></td><td>Longitudinal</td><td>Lateral</td></tr>
<tr><td></td><td>20</td><td>20</td></tr>
<tr><td colspan="3"><u>Vehicle Trajectory</u>
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.</td><td>Vehicle came to rest 119 m (390 ft) downstream and 15 m (50 ft) behind the point of impact.</td><td>Pass</td></tr>
<tr><td colspan="3">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.</td><td>Velocity change 20.6 km/h (12.8 mi/h) (<24.1 km/h (15 mi/h); exit angle 12.3 degrees (<14.4 degrees or 60 percent of 24.0 degrees)</td><td>Pass</td></tr>
</table>

Table 12. Assessment of results of test 471470-5 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-5 | Test Date: 05/30/91

<table>
<tr><th colspan="2">Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td colspan="4">Structural Adequacy</td></tr>
<tr><td>A.</td><td>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 accceptable.</td><td>The vehicle did not penetrate or go over the barrier and was smoothly redirected.</td><td>Pass</td></tr>
<tr><td>D.</td><td>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.</td><td>No debris showed potential for penetrating passenger compartment or presenting unduc hazard to other traffic.</td><td>Pass</td></tr>
<tr><td colspan="4">Occupant Risk</td></tr>
<tr><td>E.</td><td>The vehicle shall remain upright during and after collision although mbdcrate roll, pitching and yawing arc accceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.</td><td>Vehicle remained upright and stable during collision. There was no deformation or intrusion into the passenger compartment.</td><td>Pass</td></tr>
<tr><td rowspan="2">F.</td><td>Impact velocity of hypothetical front seat passenger against the vchiclc interior shall be less than<table><tr><th colspan="2">Occupant Impact Velocity Limits (m/s)</th></tr><tr><td>Longitudinal</td><td>Lateral</td></tr><tr><td>12.2 (40 ft/s)</td><td>9.1 (30 ft/s)</td></tr></table></td><td>Longitudinal Impact Vclocity = 4.5 m/s (14.7 ft/s)
Lateral Impact Velocity = 4.3 m/s (14.2 ft/s)</td><td>N/A</td></tr>
<tr><td>and vehicle highest 10-ms average accelerations subsequent to instant of hypothetical passenger contact should be less than:<table><tr><th colspan="2">Occupant Ridedown Acceleration Limits (g's)</th></tr><tr><td>Longitudinal</td><td>Lateral</td></tr><tr><td>20</td><td>20</td></tr></table></td><td>Longitudinal Occupant Ridedown = -3.5 g's
Latcral Occupant Ridedown = 9.7 g's</td><td>N/A</td></tr>
<tr><td colspan="4">Vehicle Trajectory</td></tr>
<tr><td>H.</td><td>After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.</td><td>Vchicle came to rest 86.9 m (285 ft) downstream and even with the point of impact.</td><td>Pass</td></tr>
<tr><td>I.</td><td>In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test articlc 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.</td><td>Velocity change 26.9 km/h (16.7 mi/h) (>24.1 km/h (15 mi/h); exit angle 10.4 degrees (<15.1 degrees or 60 percent of 25.1 degrees)</td><td>Pass</td></tr>
</table>

of 24.1 km/h (15 mi/h), but the exit angle of 10.4 degrees was considerably less than 60 percent of the impact angle.

In summary, all three long-span nested W-beam guardrail designs for use over culverts performed very well in crash tests and met all evaluation criteria set forth in NCHRP Report 230. It is therefore recommended that the nested W-beam guardrail design without the W-beam rail section in the rear of the guardrail be approved for field implementation for culverts with clear spans up to 5.72 m (18 ft, 9 in).

V. PENNSYLVANIA TRANSITION DESIGN

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. This chapter presents 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 NCHRP Report 230.

5.1 TEST INSTALLATION

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 ft) of W-beam approach guardrail and transition. Figure 14 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 813-mm- (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, 610-mm- (24-in-) wide and 914-mm- (36-in-) deep reinforced concrete foundation.

A Type C drainage inlet, details of which are shown in figure 15, was constructed and installed at the end of the wingwall. To facilitate a smooth transition from the drainage inlet to the wingwall, a 203-mm- (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 203-mm (8-in) curb of the drainage inlet. The drainage inlet was connected to the transition curb block of the wingwall with two 305-mm- (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-foot) 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 using a modified terminal connector, as detailed in figure 16. The top of the posts and W-beams extended 787 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.

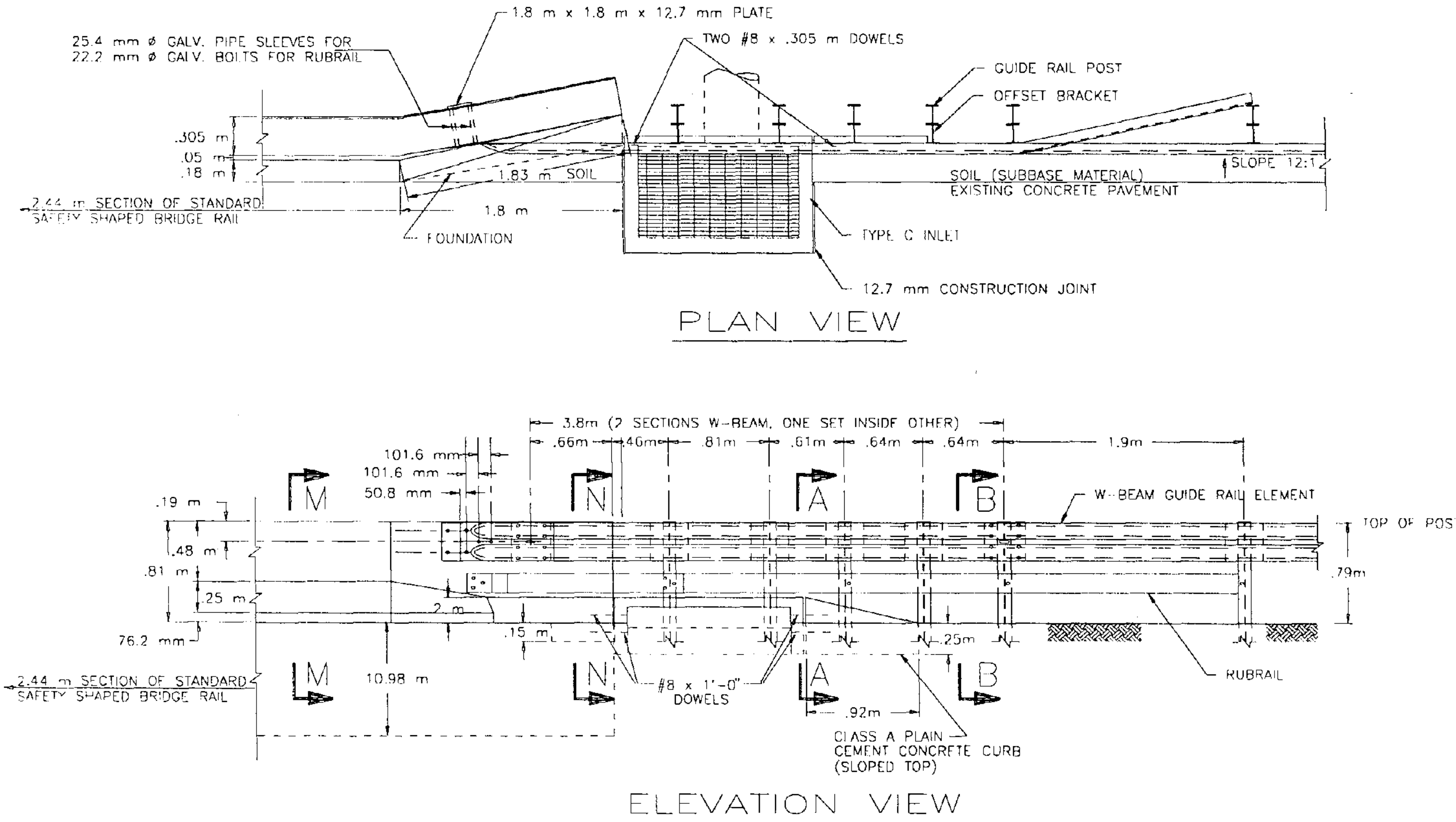
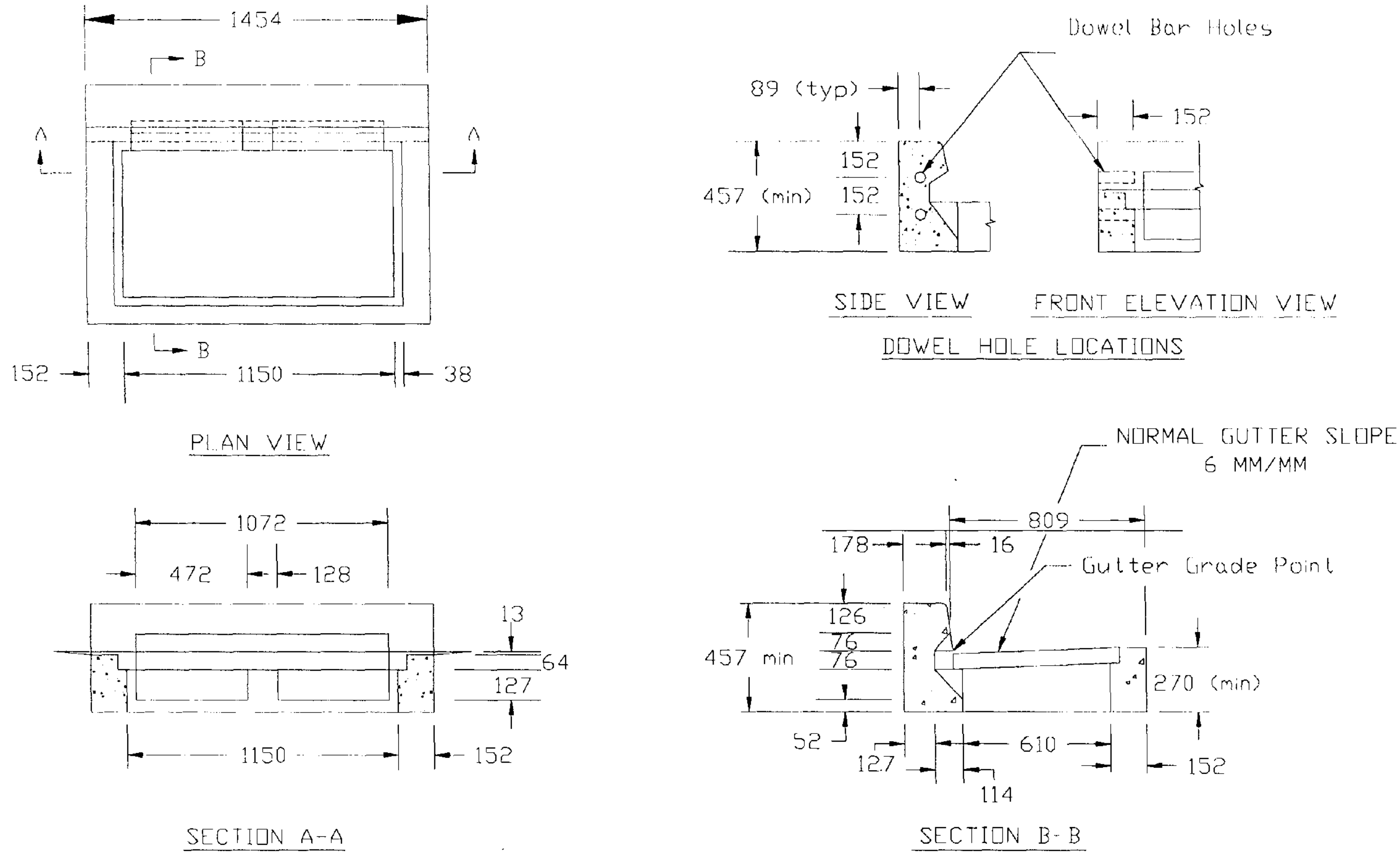


Figure 14. Construction details for Pennsylvania bridge rail transition.



TYPE C

Figure 15. Type C drainage inlet.

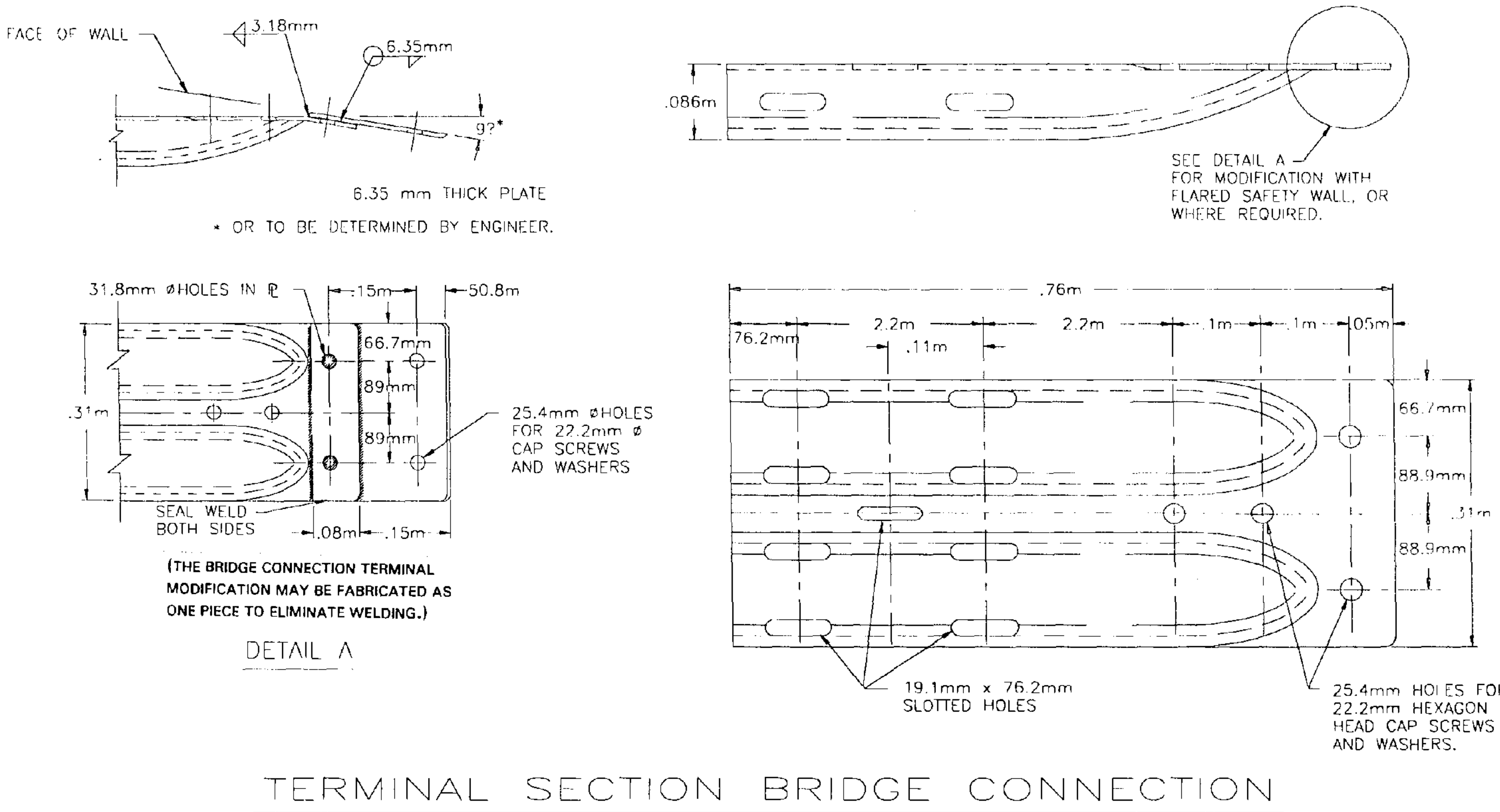


Figure 16. Modified terminal connector.

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 17.

5.2 TEST NUMBER 471470-3 (NCHRP REPORT 230 TEST DESIGNATION 30)

Test vehicle: 1979 Cadillac Coupe de Ville Test inertia weight: 2043 kg (4500 lb) Gross static weight: 2120 kg (4670 lb)	Impact speed: 99.0 km/h (61.5 mi/h) Impact angle: 25.4 degrees

The vehicle impacted the transition system approximately midspan of posts 2 and 3. The vehicle began to redirect shortly after initial impact. The right front tire of the vehicle impacted the curb face of the drainage inlet and the tire flattened. The tire climbed on top of the drainage inlet curb and the right front of the vehicle started to rise. The right rear of the roof began to deform 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 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, reaching a maximum dynamic deflection of 64 mm (2.5 in) at the top. The vehicle became parallel to the transition system traveling at 68.5 km/h (42.6 mi/h). The rear of the vehicle impacted the transition system and the vehicle exited the transition traveling at 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. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 18.

The total length of contact of the vehicle with the transition system was 5.3 m (17.5 ft). The maximum 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 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).

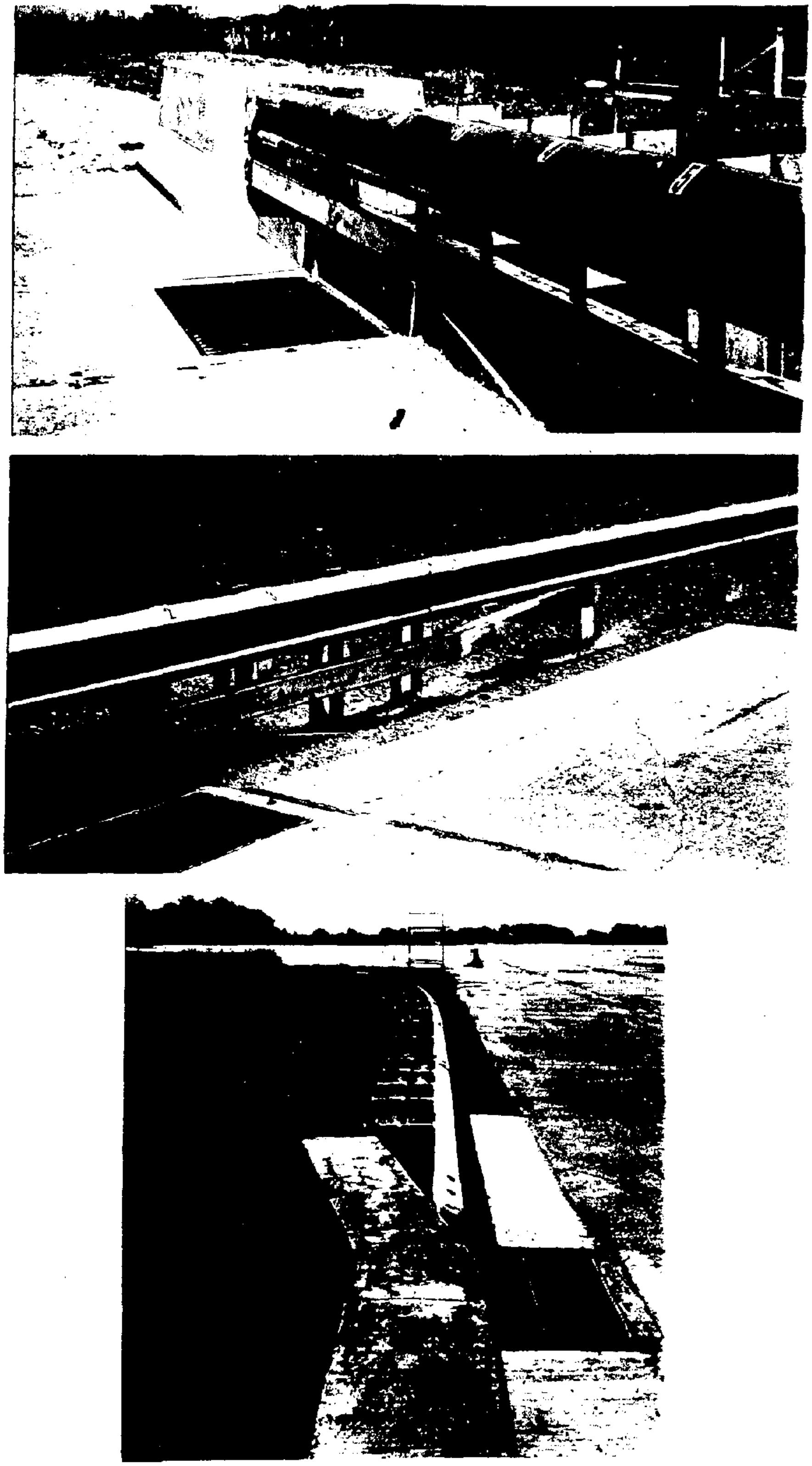
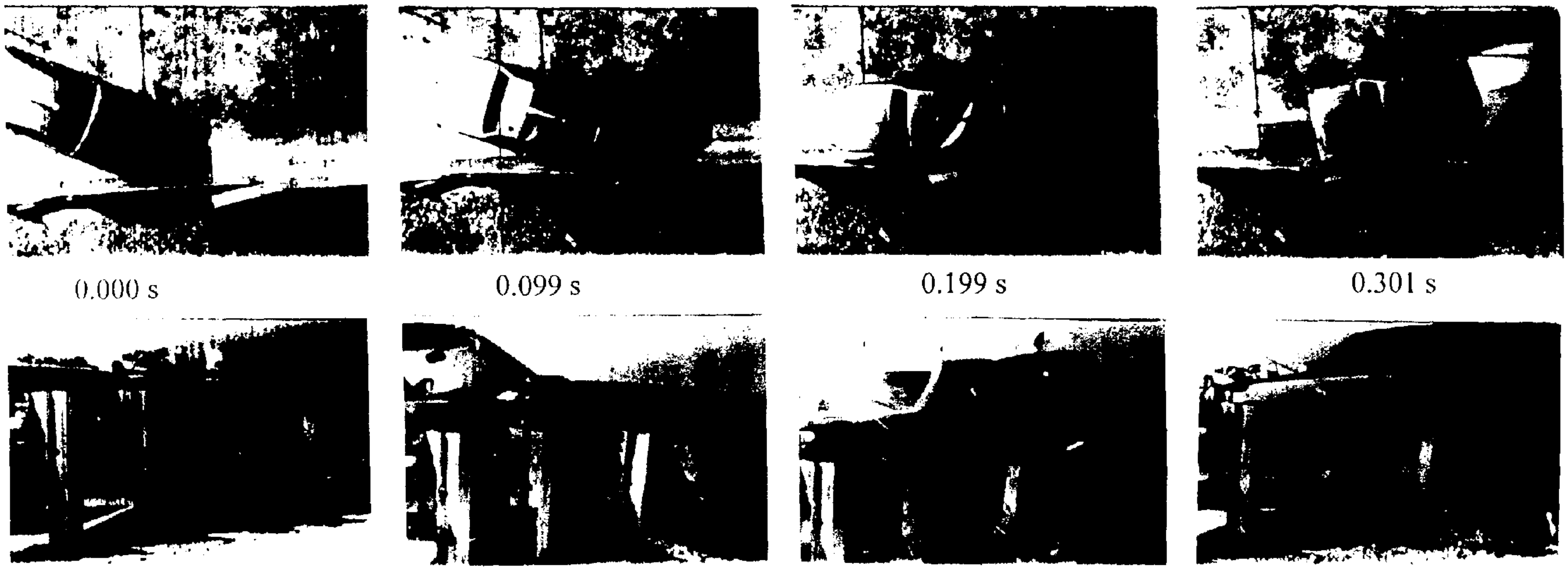
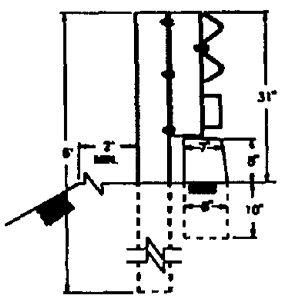


Figure 17. Photographs of test installation 471470-3.





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 18. Summary of results for test 471470-3.

The vehicle sustained 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). Damage occurred 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.

5.3 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 prior to adjustment for location of vehicle c.g. (23.7 g), but fell to just within the acceptable limit after the adjustment (19.5 g). It should be noted 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.

Although the Pennsylvania transition design met the evaluation criteria as shown table 13, the impact performance of this transition design is considered very marginal. Of

Table 13. Assessment of results of test 471470-3 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-3 | 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

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 may not happen 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 damages with considerable deformation and intrusion into the passenger compartment. Considering all this, it is recommended that the transition design be improved prior to actual field applications.

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 could be placed 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 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.

VI. WASHINGTON, DC, PL-1 BRIDGE RAIL DESIGN

The Washington, DC, Department of Public Works, in cooperation with the FHWA, has designed a bridge railing that is aesthetically pleasing for use with bridges on highways through historic districts. The bridge railing is to be evaluated with two full-scale crash tests in accordance with requirements for a performance level 1 (PL-1) bridge railing of the 1989 AASHTO *Guide Specifications for Bridge Railings*:

1. An 817-kg (1800-lb) passenger car impacting the bridge railing at a nominal speed of 80.5 km/h (50 mi/h) and at an angle of 20 degrees.
2. A 2452-kg (5400-lb) pickup truck impacting the bridge railing at a nominal speed of 72.5 km/h (45 mi/h) and at an angle of 20 degrees.

The first crash test (test no. 471470-6) with the small passenger car was conducted on the original design of the Washington, DC, bridge rail, and its performance was judged to be unsatisfactory. The bumper of the vehicle underrode the beam element of the bridge railing, allowing the front tire to impact and snag severely on the posts. The design was then modified by replacing the bottom TS 102-mm × 76.2-mm × 6.4-mm (4-in × 3-in × 1/4-in) box-beam sections with wider TS 152 mm × 50.8 mm × 6.4 mm (6 in × 2 in × 1/4 in) box-beam sections and moving the box-beam sections forward to be flush with the face of the posts on the traffic side. The two crash tests required for a PL-1 bridge railing were then conducted on the modified bridge rail design. The first test (test no. 471470-8) was a repeat of the small passenger car test and the second test (test no. 471470-9) was the pickup truck strength test. The modified bridge railing performed satisfactorily in both tests.

This chapter summarizes the full-scale crash tests and performance evaluation of the Washington, DC, historic bridge railing. Testing and evaluation was performed according to guidelines outlined in the 1989 AASHTO *Guide Specifications for Bridge Railings.*

6.1 TEST INSTALLATION

The overall test installation consisted of a 23.5-m- (77-ft-) long simulated bridge deck and a 22.9-m- (75-ft-) long bridge railing, as shown in figure 19. The simulated bridge deck was attached to an existing simulated bridge deck foundation and cantilevered out for a length of 1.02 m (40 in). It should be noted that the bridge railing is typically used with a sidewalk behind the railing for pedestrian traffic. However, for the purpose of evaluating the impact performance of the bridge railing, the pedestrian sidewalk was not deemed necessary and thus was not included in the test installation. Details of the bridge deck and steel reinforcement are shown in figure 20. The bridge railing sat on top of a 152-mm- (6-in-) high curb with cutouts for anchoring the base plates of the metal bridge railing posts.

The original bridge railing design, details of which are shown in figure 21, consisted of a TS 203-mm × 152-mm × 6.4-mm (8-in × 6-in × 1/4-in) box beam welded onto the tops

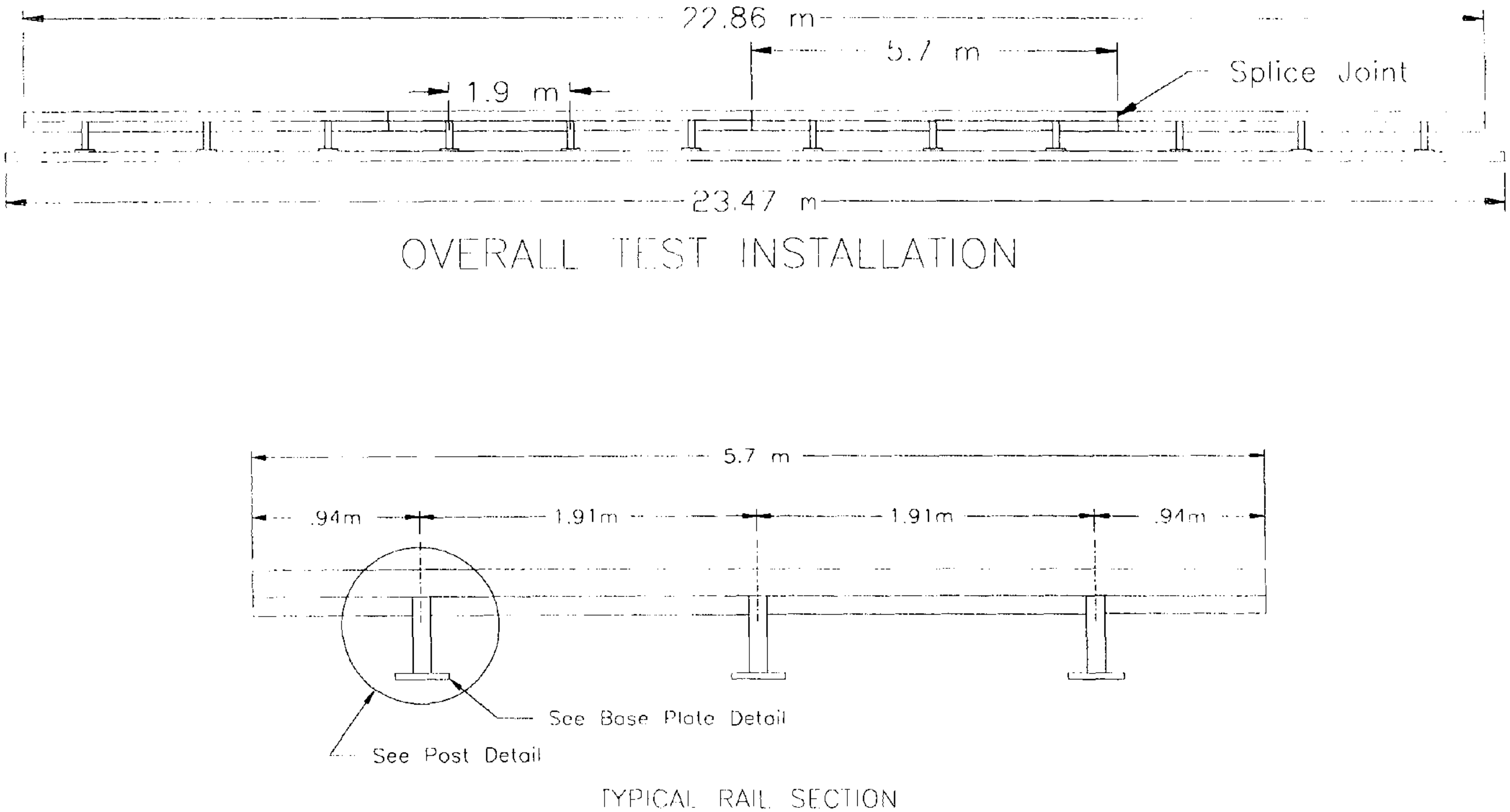


Figure 19. Washington, DC, historic bridge rail test installation.

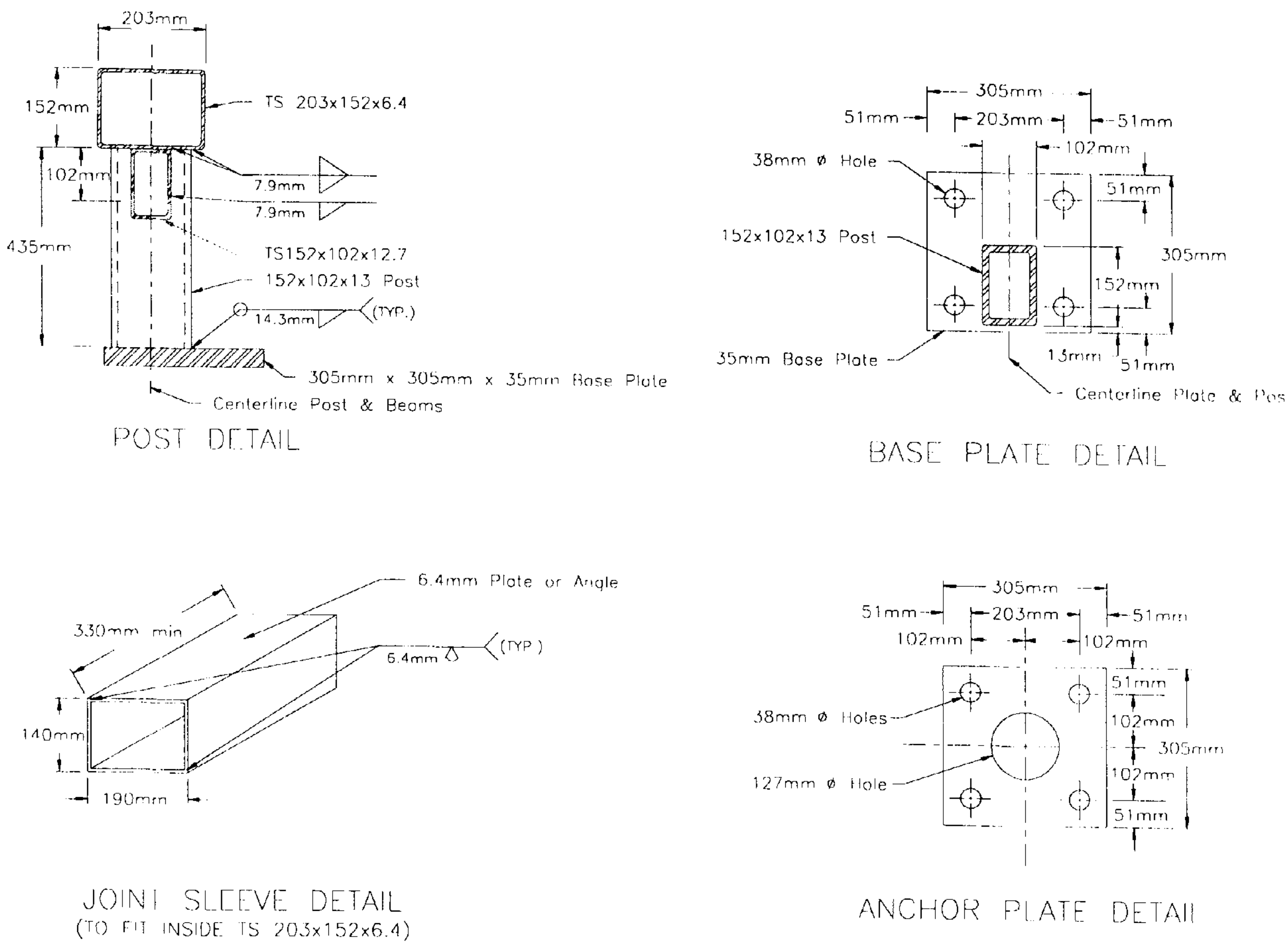


Figure 19. Washington, DC, historic bridge rail test installation (continued).

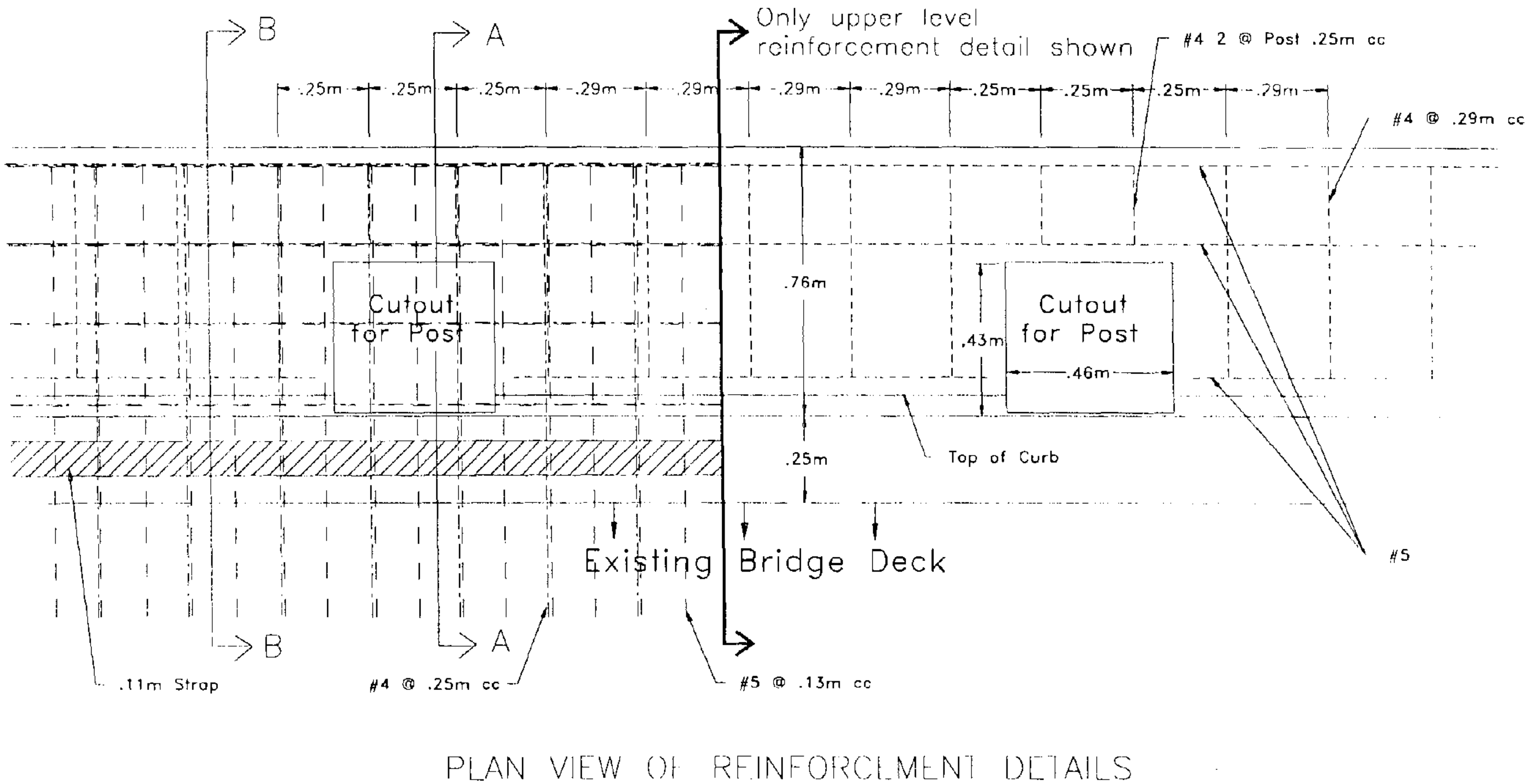
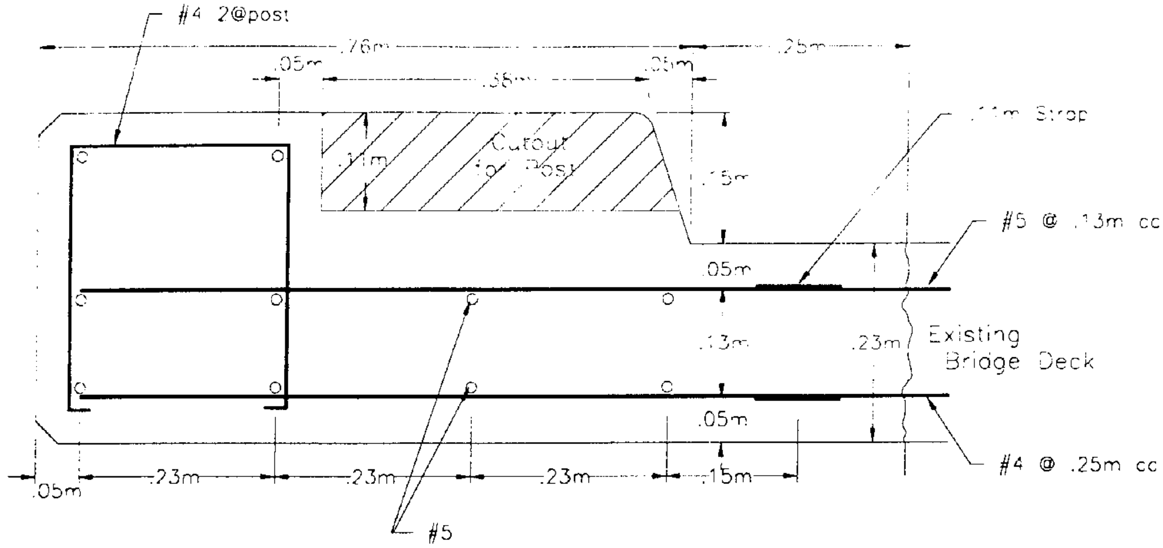
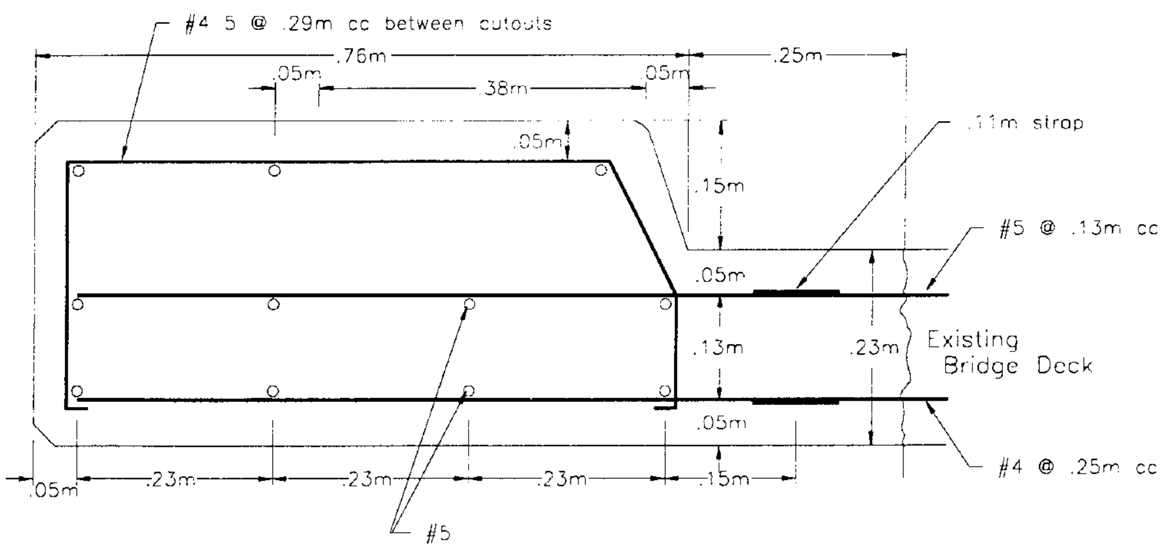


Figure 20. Steel reinforcement details for Washington, DC, historic bridge rail.



SECTION A-A



SECTION B-B

Figure 20. Steel reinforcement details for Washington, DC, historic bridge rail (continued).

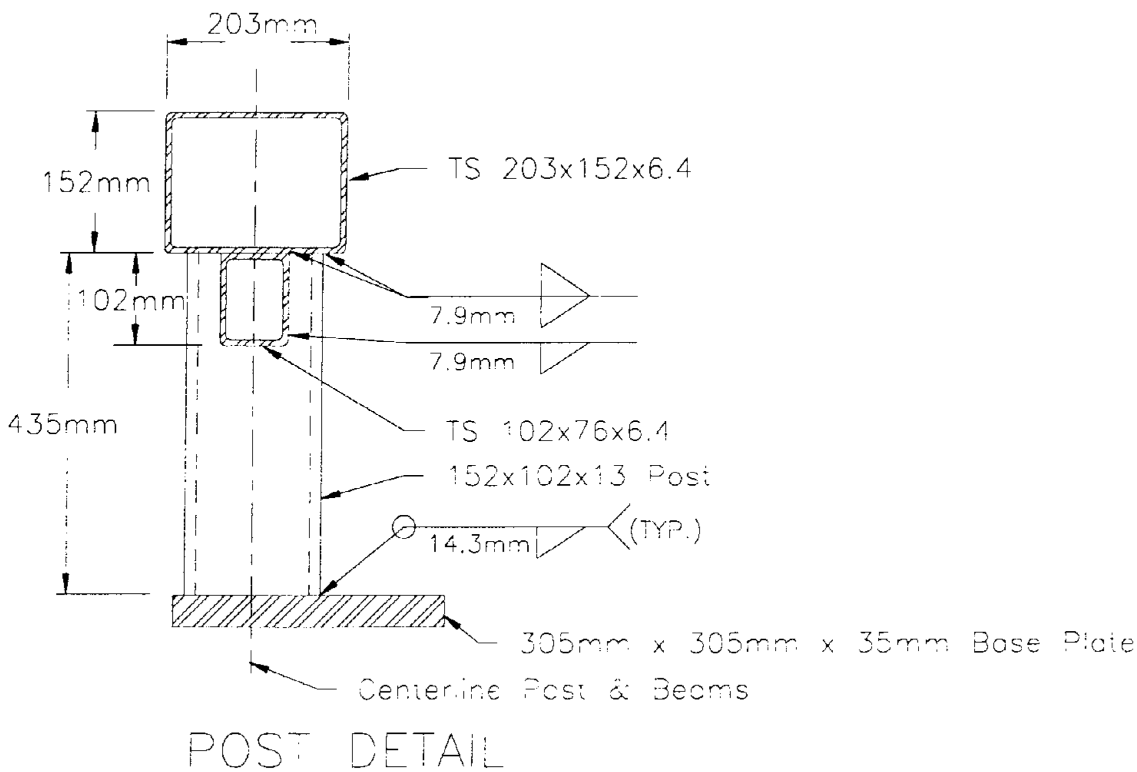


Figure 21. Original post details.

of 152-mm × 102-mm × 12.7-mm (6-in × 4-in × 1/2-in) posts spaced 1.9 m (6 ft, 3 in) center to center. TS 102-mm × 76-mm × 6.4-mm (4-in × 3-in × 1/4-in) box beams were placed between the posts, which were welded to the bottom of the TS 203-mm × 152-mm × 6.4-mm (8-in × 6-in × 1/4-in) box beam and to the sides of the posts. The purpose of the bottom box-beam sections was to reduce the height of the opening beneath the top box-beam rail element.

The bridge railing was fabricated in four sections, each 5.7 m (18 ft, 8 in) in length. The sections were connected with joint sleeves and welded in place after installation. The bridge railing would typically have an expansion joint and anchorage at both ends. However, these details were deemed unnecessary for the purpose of evaluating the impact performance of the bridge railing and thus were not included for the test installation.

Each railing post was welded to a 305-mm × 305-mm × 25.4-mm (12-in × 12-in × 1-in) base plate and attached to the simulated bridge deck using four 32-mm- (1-1/4-in-) diameter, high-strength bolts that were built into the bridge deck with an anchor plate. Grout pads, approximately 25.4 mm (1 in) thick, were used under the base plates to level the bridge railing and to adjust the height of the bridge railing to 686 mm (27 in). The cutouts were then backfilled with concrete after installation of the metal bridge railing. Photographs of the completed test installation are shown in figure 22.

As mentioned previously, the original design of the Washington, DC, bridge rail did not perform satisfactorily in the first crash test (test no. 471470-6) with an 820-kg passenger car. The bridge rail design was then modified by replacing the bottom TS 102-mm × 76.2-mm × 6.4-mm (4-in × 3-in × 1/4-in) box-beam sections with wider TS 152-mm × 50.8-mm × 6.4-mm (6-in × 2-in × 1/4-in) box-beam sections and moving the box-beam sections forward to be flush with the face of the posts on the traffic side. These box-beam sections were welded to the bottom of the top box-beam rail element and to the sides of the posts. The modified bridge rail design was then crash tested in the next two crash tests (test nos. 471470-8 and 471470-9). Photographs of the modified test installation are shown in figure 23.

6.2 TEST NUMBER 471470-6 (AASHTO PL-1 SMALL CAR TEST)

Test vehicle: 1987 Yugo GV	Impact speed: 82.4 km/h (51.2 mi/h)
Test inertia weight: 817 kg (1800 lb)	Impact angle: 20.1 degrees
Gross static weight: 894 kg (1970 lb)	

The vehicle impacted the bridge railing midspan between posts 3 and 4, or approximately 5.72 m (18 ft, 9 in) downstream from the upstream end of the bridge railing. As the vehicle bumper contacted the bridge rail, the left front tire contacted the curb at the same time and appeared to partially air out. The vehicle bumper hit post 4 and the vehicle began to redirect. The left front tire of the vehicle mounted the curb and contacted post 4 when the roof of the vehicle began to buckle. Tire marks indicated that the left front tire

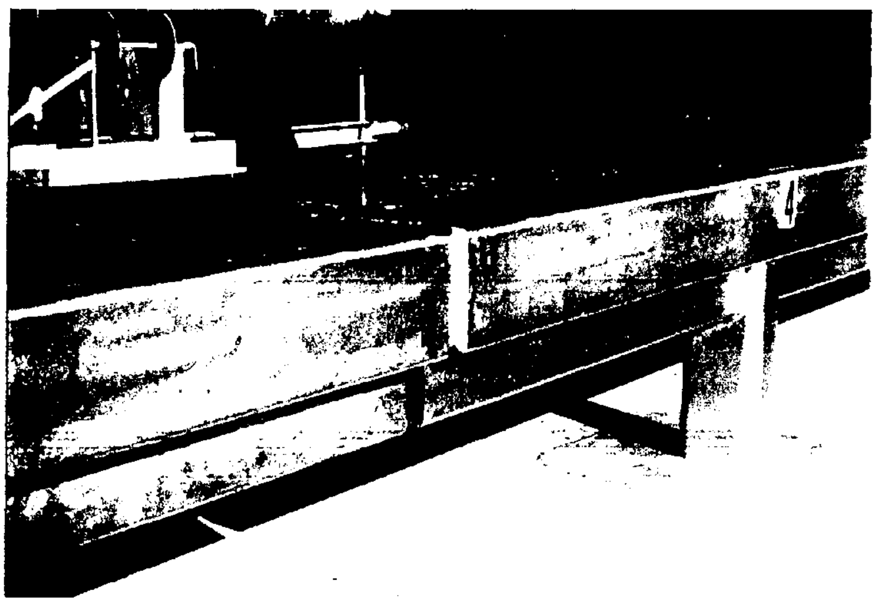


Figure 22. Photographs of test installation 471470-6.

Figure 23. Photographs of modified test installation.

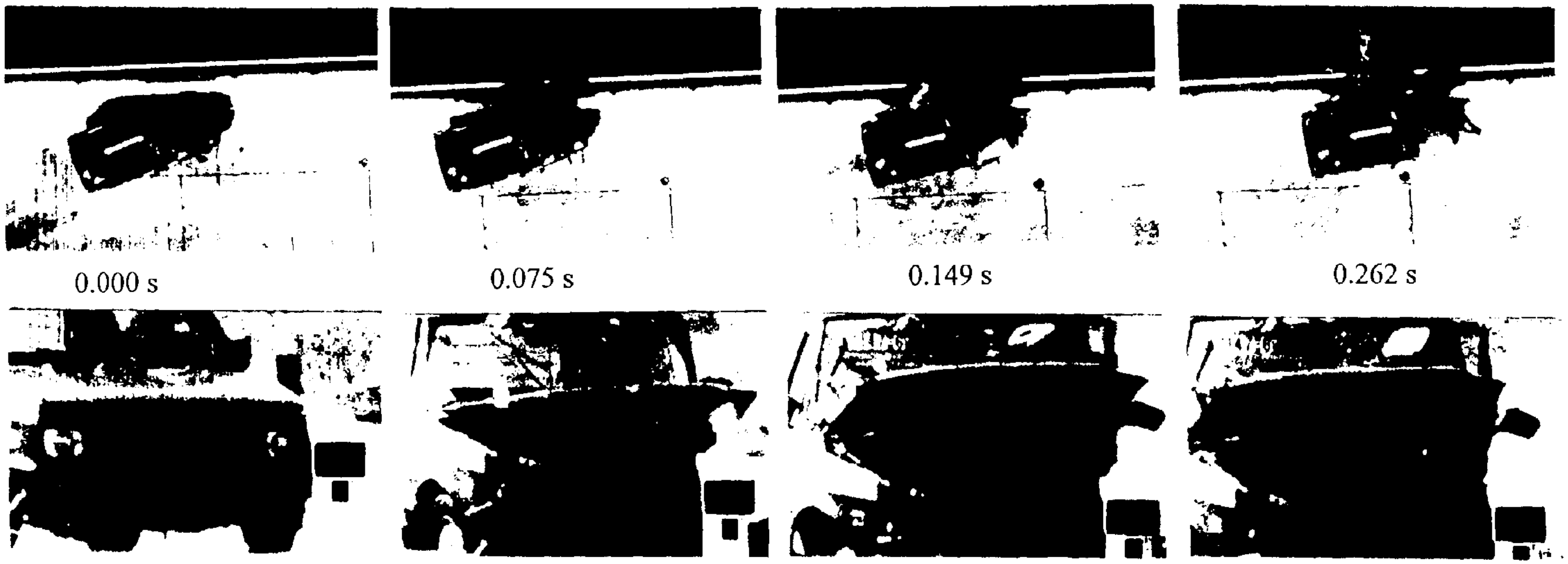
folded and went underneath the box beam and overlapped post 4 by a distance of 254 mm (10 in). The tires began to pull to the left and the front bumper began to come apart, extending behind the rail. There was sudden left steer input again, and the front bumper of the vehicle contacted post 5. The vehicle was traveling parallel to the bridge rail system at a speed of 62.9 km/h (39.1 mi/h). The left front tire impacted post 5, again pulling the front tires to the left. The vehicle exited the bridge rail traveling at a speed of 55.5 km/h (34.5 mi/h) with an exit angle of 1.5 degrees. After the vehicle exited from the bridge rail, the bumper struck post 6, cleared the rail and the left front tire dropped off the curb. Due to the damage sustained by the left front tire and the orientation of the front tires, the vehicle turned back toward the bridge rail after exiting from the initial impact and impacted it again near post 8. The vehicle then rode along and off the end of the bridge rail. The brakes were applied after the vehicle cleared the test installation and the vehicle came to rest 32.0 m (105 ft) downstream from and 7.6 m (25 ft) behind the point of initial impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 24.

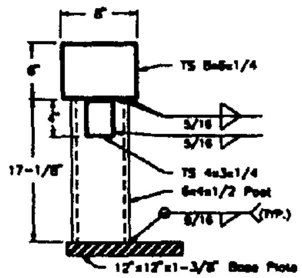
There was no permanent deformation of the bridge railing. The total length of contact for the initial impact was 4.0 m (13.0 ft). Tire marks extended 254 mm (10.0 in) under the rail element at post 4. The vehicle's sway bar, left strut, and inner C.V. joint were damaged. The windshield was broken, and the roof, floor pan, and instrument panel were bent. There was damage to the front bumper, hood, grill, radiator, left front quarter panel, left rear door and glass, left rear quarter panel, and the rear bumper. The firewall and floor pan were pushed into the steering column and clutch pedal for a maximum intrusion into the occupant compartment of 356 mm (14.0 in). The wheelbase on the right side was shortened from 2.1 m (84.0 in) to 1.7 m (66.5 in). The left front tire and rim were damaged from contact with the posts and the rear tire and rim were damaged in later contact with the curb. Maximum crush to the vehicle was 254 mm (10.0 in) at the left front corner at bumper height.

6.3 TEST NUMBER 471470-8 (AASHTO PL-1 SMALL CAR TEST)

Test vehicle: 1988 Ford Festiva	Impact speed: 80.0 km/h (49.7 mi/h)
Test inertia weight: 817 kg (1800 lb)	Impact angle: 21.5 degrees
Gross static weight: 892 kg (1965 lb)	

This test was a repeat of the small car test with the modified bridge rail design. The vehicle impacted the bridge railing midspan between posts 3 and 4, or approximately 5.72 m (18 ft, 9 in) downstream from the upstream end of the bridge railing. As the vehicle bumper contacted the bridge rail, the left front tire contacted the curb at the same time. The front of the vehicle began to shift to the right, the left front tire aired out, and the vehicle began to redirect. The left front tire of the vehicle mounted the curb and contacted post 4. Tire marks indicated that the left front tire went underneath the box beam a distance of 64 mm (2.5 in) just before impacting post 4. The vehicle became parallel to the bridge rail system traveling at 65.3 km/h (40.6 mi/h) after which the rear of the vehicle contacted the rail. The vehicle exited the bridge rail traveling at 64.5 km/h (40.1 mi/h) with an exit angle of 3.5 degrees. The





POST DETAIL

Test No.	7147-6	Impact Speed	82.4 km/h (51.2 mi/h)
Date	09/17/91	Impact Angle	20.1 deg
Test Installation	Washington, DC, Historic Bridge Rail	Speed at Parallel	62.9 km/h (39.1 mi/h)
		Exit Speed	55.5 km/h (34.5 mi/h)
Installation Length	23 m (75 ft)	Exit Trajectory	1.5 deg
Max. Dynamic Deflection	nil	Vehicle Accelerations	
Max. Perm. Deformation	none	(Max. 0.050-s avg)	
Test Vehicle	1987 Yugo GV	Longitudinal	-8.5 g's
Vehicle Weight		Lateral	- 9.4 g's
Test Inertia	817 kg (1800 lb)	Occupant Impact Velocity at true c.g.	
Gross Static	894 kg (1970 lb)	Longitudinal	7.5 m/s (24.7 ft/s)
Vehicle Damage Classification		Lateral	5.1 m/s (16.6 ft/s)
TAD	11FL6 & 11LD7	Occupant Ridedown Accelerations	
CDC	11FLEK4 & 11LDEW4	Longitudinal	-6.5 g's
Maximum Vehicle Crush	254 mm (10.0 in)	Lateral	-9.9 g's

Figure 24. Summary of results for test 471470-6.

brakes were applied after the vehicle cleared the test installation and the vehicle came to rest 59 m (195 ft) downstream from and 29 m (95 ft) forward of the point of initial impact. A summary of pertinent data from the electronic instrumentation, high-speed, film and field measurements is given in figure 25.

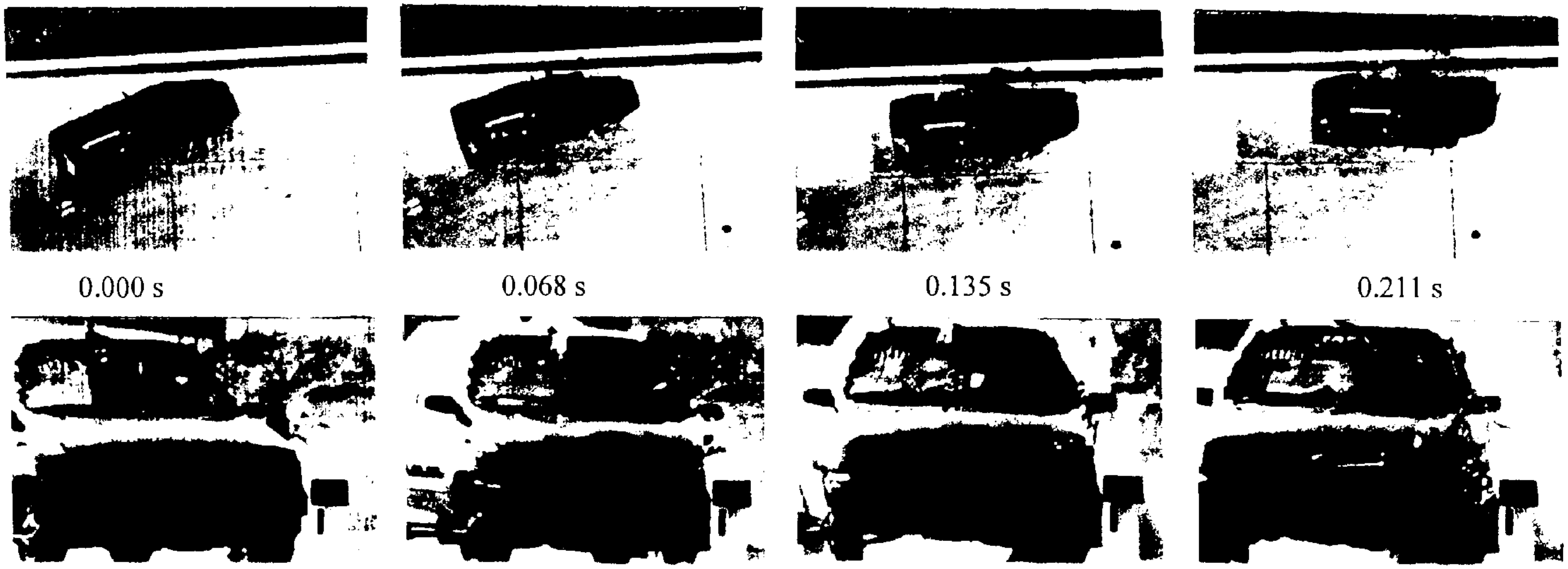
There was no permanent deformation of the bridge railing. The total length of contact with the rail was 2.5 m (8.3 ft). Tire marks extended 64 mm (2.5 in) under the rail element just before post 4. The vehicle's left strut and C.V. joint were damaged. The driver's window was broken and there was damage to the front bumper, hood, grill, radiator, left front quarter panel, left door, left rear quarter panel, and the rear bumper. The wheelbase on the left side was shortened from 2.3 m (90.25 in) to 2.2 m (87.0 in). The left front tire and rim were damaged from contact with the curb and post 4. Maximum crush to the vehicle was 216 mm (8.5 in) at the left front corner at bumper height.

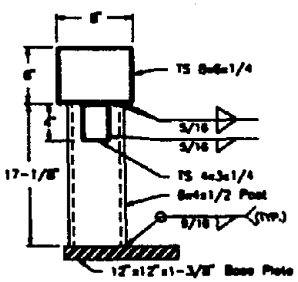
6.4 TEST NUMBER 471470-9 (AASHTO PL-1 PICKUP TRUCK TEST)

Test vehicle: 1986 Chevrolet Pickup	Impact speed: 76.7 km/h (47.7 mi/h)
Test inertia weight: 2452 kg (5400 lb)	Impact angle: 20.6 degrees
Gross static weight: 2527 kg (5565 lb)	

The vehicle impacted the bridge railing midspan between posts 3 and 4, or approximately 5.72 m (18 ft, 9 in) downstream from the upstream end of the bridge railing. The left front tire contacted the curb, and then the vehicle began to redirect. The left front tire of the vehicle mounted the curb and contacted post 4. Tire marks indicated that the left front tire did not go underneath the box beam rail element. The vehicle began traveling parallel to the bridge rail system at 71.4 km/h (44.4 mi/h) after which the rear of the vehicle contacted the rail. The vehicle exited the bridge rail traveling at 70.3 km/h (43.7 mi/h) with an exit angle of 5.4 degrees. The brakes were applied after the vehicle cleared the test installation and the vehicle came to rest 82 m (270 ft) downstream of impact and 9 m (30 ft) toward traffic lanes. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 26.

There was no permanent deformation of the bridge railing. The total length of contact with the rail was 3.9 m (12.9 ft). Tire marks indicated that the tire did not go under the rail element. The vehicle's driver-side window was broken and there was damage to the front bumper, hood, grill, left front quarter panel, left door, left rear quarter panel, and the rear bumper. The left front and rear rims were damaged from contact with the curb and rail element. Maximum crush to the vehicle was 254 mm (10.0 in) at the left front corner at bumper height.



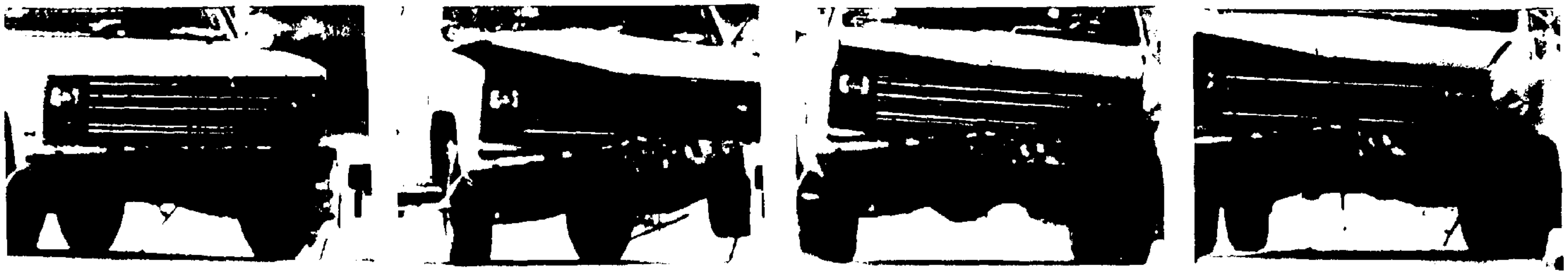


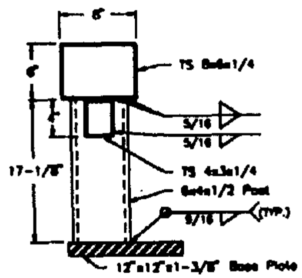
Test No.	7147-8
Date	12/10/91
Test Installation	Washington, DC, Historic Bridge Rail
Installation Length	23 m (75 ft)
Max. Dynamic Deflection	nil
Max. Perm. Deformation	none
Test Vehicle	1988 Ford Festiva
Vehicle Weight	
Test Inertia	817 kg (1800 lb)
Gross Static	892 kg (1965 lb)
Vehicle Damage Classification	
TAD	11FL2 & 11LD3
CDC	11FLEK1 & 11LDEW3
Maximum Vehicle Crush	216 mm (8.5 in)

Impact Speed	80.0 km/h (49.7 mi/h)
Impact Angle	21.5 deg
Speed at Parallel	65.3 km/h (40.6 mi/h)
Exit Speed	64.5 km/h (40.1 mi/h)
Exit Trajectory	3.5 deg
Vehicle Accelerations (Max. 0.050-s avg)	
Longitudinal	-6.0 g's
Lateral	-10.2 g's
Occupant Impact Velocity at true c.g.	
Longitudinal	4.3 m/s (14.2 ft/s)
Lateral	5.7 m/s (18.7 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-1.4 g's
Lateral	-6.9 g's

Figure 25. Summary of results for test 471470-8.

0.000 s 0.094 s 0.188 s 0.281 s





POST DETAIL

Test No.	7147-9
Date	12/16/91
Test Installation	Washington, DC, Historic Bridge Rail
Installation Length	23 m (75 ft)
Max. Dynamic Deflection	nil
Max. Perm. Deformation	none
Test Vehicle	1986 Chevrolet Pickup
Vehicle Weight	
Test Inertia	2352 kg (5400 lb)
Gross Static	2527 kg (5565 lb)
Vehicle Damage Classification	
TAD	11FL2 & 11LD3
CDC	11FLEK2 & 11LDEW2
Maximum Vehicle Crush	254 mm (10.0 in)

Impact Speed	76.7 km/h (47.7mi/h)
Impact Angle	20.6 deg
Speed at Parallel	71.4 km/h (44.4 mi/h)
Exit Speed	70.3 km/h (43.7 mi/h)
Exit Trajectory	5.4 deg
Vehicle Accelerations (Max. 0.050-s avg)	
Longitudinal	-3.6 g's
Lateral	-8.7 g's
Occupant Impact Velocity at true c.g.	
Longitudinal	2.7 m/s (8.9 ft/s)
Lateral	4.8 m/s (15.6 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-2.2 g's
Lateral	- 14.1 g's

Figure 26. Summary of results for test 471470-9.

6.5 SUMMARY OF FINDINGS

In the first test (test no. 471470-6) with the original bridge rail design, the vehicle was redirected and did not penetrate or go over the bridge railing. The bridge railing received only minimal damage and 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 bridge railing and after exiting the test installation. However, the vehicle sustained extensive damage and there was considerable deformation and intrusion into the passenger compartment. The exit trajectory of the vehicle was judged not to pose any potential hazard to adjacent traffic. The occupant impact velocities and ridedown accelerations were within the acceptable limits.

The impact performance of the original Washington, DC, historic bridge rail design was judged to be unsatisfactory according to evaluation criteria set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings*, as summarized in table 14. The bumper of the vehicle underrode the beam element of the bridge rail and impacted the posts, resulting in the bumper being torn off the vehicle. The left front tire of the vehicle snagged extensively on the posts, pushing the tire back into the wheel well, resulting in considerable deformation and intrusion into the passenger compartment in the firewall and floor pan area.

Review of the results of the first test suggested that the unsatisfactory performance of the original bridge rail design was caused by the bumper underriding the beam element of the bridge rail, resulting in the bumper impacting the posts head-on and the left front tire of the vehicle snagging severely on the posts. It was therefore recommended that the bottom TS 102- mm × 76.2-mm × 6.4-mm (4-in × 3-in × 1/4-in) box-beam sections be replaced with wider TS 152-mm × 50.8-mm × 6.4-mm (6-in × 2-in × 1/4-in) box-beam sections and the box-beam sections be moved forward to be flush with the face of the posts on the traffic side. This would reduce the potential for the bumper and the front wheel of the vehicle to underride the beam element of the bridge rail and impact the posts directly.

The modified Washington, DC, historic bridge rail was then crash tested with successful results. The second test (test no. 471470-8) was a repeat of the first test with a small passenger car on the modified bridge rail design. Summaries of the performance evaluation according to evaluation criteria set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings* are presented in table 15. The vehicle was redirected smoothly and did not penetrate or go over the bridge railing. The bridge railing received only minimal damage and 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 bridge railing and after exiting the test installation. The vehicle sustained moderate damage with essentially no deformation or intrusion into the passenger compartment. The occupant impact velocities and ridedown accelerations were well within the acceptable limits.

Table 14. Assessment of results of test 471470-6 (according to 1989 AASHTO Guide).

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a. The test 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.	The bridge rail contained the vehicle, i.e., the vehicle did not penetrate or go over the bridge rail.	Pass
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.	No debris showed potential for penetrating the passenger compartment or presenting undue hazard to other traffic.	Pass
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was intrusion and deformation into the passenger compartment.	Fail
d. The vehicle shall remain upright during and after collision.	The vehicle remained upright and stable during and after the collision.	Pass
e. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	N/A
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment 0.53 — Marginal	N/A
g. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 7.5 (24.7); Lateral 5.1 (16.6) Occupant Ridedown Accelerations - g's Longitudinal -6.5; Lateral -9.9	Pass
h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (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 6 m (20 ft) from the line of the traffic face of the railing.	Exit angle at loss of contact was 1.5 degrees. Vehicle came to rest 32 m (105 ft) down and 8 m (25 ft) behind the point of impact.	N/A

*a, b, c, d, and g are required. e, f, and h are desired.

Table 15. Assessment of results of test 471470-8 (according to 1989 AASHTO Guide).

	AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a.	The test 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.	The bridge rail contained the vehicle, i.e., the vehicle did not penetrate or go over the bridge rail.	Pass
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.	No debris showed potential for penetrating the passenger compartment or presenting undue hazard to other traffic.	Pass
c.	Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no intrusion or deformation into the passenger compartment.	Pass
d.	The vehicle shall remain upright during and after collision.	The vehicle remained upright and stable during and after the collision.	Pass
e.	The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	N/A
f.	The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment 0.31 — Fair	N/A
g.	The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal: 9.2 (30) — Lateral: 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal: 15 — Lateral: 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal: 4.3 (14.2) — Lateral: 5.7 (18.7) Occupant Ridedown Accelerations - g's Longitudinal: -1.4 — Lateral: -6.9	Pass
h.	Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (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 6 m (20 ft) from the line of the traffic face of the railing.	Exit angle at loss of contact was 3.5 degrees. Vehicle came to rest 59 m (195 ft) down and 29 m (95 ft) forward of point of impact.	N/A

*a, b, c, d and g are required. e, f, and h are desired.

The modified bridge rail design was then crash tested with a 2451-kg (5400-lb) pickup truck in the third test (test no. 471470-9). Summaries of the performance evaluation for this test, according to evaluation criteria set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings,* are presented in table 16. The vehicle was smoothly redirected and did not penetrate or go over the bridge railing. The bridge railing received only minimal damage and 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 bridge railing and after exiting the test installation. The vehicle sustained moderate damage with essentially no deformation or intrusion into the passenger compartment.

In summary, the modified Washington, DC, historic bridge rail design performed satisfactorily in both crash tests and met all requirements as outlined under the 1989 AASHTO *Guide Specifications for Bridge Railings.* It is, therefore, recommended that the modified Washington, DC, historic bridge railing design be approved for field implementation.

Two observations unrelated to the impact performance of the bridge railing are presented herein for consideration. One observation is that repair of the bridge rail may be a potential problem. The base plates of the posts and the bolts and nuts attaching the posts to the bridge deck are recessed into cutouts in the curb on the bridge deck. The cutouts are then backfilled with concrete after installation of the bridge rail. If the bridge rail was damaged to such an extent as to require replacement of a section of the rail, the concrete in the cutouts will have to be manually chipped out before workers can get to the bolts and nuts to remove the posts. Also, this increases the likelihood of the threads in the anchor bolts being damaged, which would further complicate removal of the posts.

The second observation is that the continuous welding used to attach the bottom TS 152-mm × 50.8-mm × 6.4-mm (6-in × 2-in × 1/4-in) box-beam sections to the top TS 203-mm × 152-mm × 6.4-mm (8-in × 6-in × 1/4-in) box beam caused the bridge rail system to warp significantly during fabrication. Heat treatment to the top beam elements was required to straighten out the bridge rail sections. It is believed that a zippered weld would be adequate from a structural standpoint, which would minimize this problem of warping due to overheating.

Table 16. Assessment of results of test 471470-9 (according to 1989 AASHTO Guide).

	AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a.	The test 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.	The bridge rail contained the vehicle, i.e., the vehicle did not penetrate or go over the bridge rail.	Pass
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.	No debris showed potential for penetrating the passenger compartment or presenting undue hazard to other traffic.	Pass
c.	Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no intrusion or deformation into the passenger compartment.	Pass
d.	The vehicle shall remain upright during and after collision.	The vehicle remained upright and stable during and after the collision.	Pass
e.	The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	N/A
f.	The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment 0.03 — Good	N/A
g.	The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal: 9.2 (30); Lateral: 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal: 15; Lateral: 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal: 2.7 (8.9); Lateral: 4.8 (15.6) Occupant Ridedown Accelerations - g's Longitudinal: -2.2; Lateral: -14.1	N/A
h.	Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (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 6 m (20 ft) from the line of the traffic face of the railing.	Exit angle at loss of contact was 5.4 degrees. Vehicle came to rest 82 m (270 ft) downstream and 9 m (30 ft) toward traffic lanes.	N/A

*a, b, c, and d are required. e, f, and h are desired.

VII. MODIFIED BREAKAWAY CABLE TERMINAL (BCT) DESIGN

One of the most widely used end treatments for W-beam guardrails is the Breakaway Cable Terminal (BCT), which was designed to minimize the spearing and rollover potential of earlier terminal designs while developing the full tensile strength of the rail for downstream impacts. For end-on impacts, the first two posts are designed to break away, allowing the W-beam rail element to buckle dynamically and bend away from the vehicle which then passes behind the terminal. The buckling and bending of the rail element is encouraged by the deletion of the post bolt washers on all but the first post, and by flaring parabolically the end section of the guardrail. For redirectional impacts, tensile strength for the W-beam is provided by a cable anchorage, which transmits tensile forces from the W-beam rail element to the base of the end post. Also, to enhance breakaway properties, foundation tubes are used for the first two posts.

The BCT terminal was developed prior to the advent of the current generation of small automobiles. While the BCT terminal had been successfully crash tested with 1021-kg (2250-lb) and 2043-kg (4500-lb) automobiles, it did not perform satisfactorily in tests with the smaller and lighter 817-kg (1800-lb) cars. The design was found to be too stiff to buckle readily under the reduced weight. In tests with the 817-kg (1800-lb) car, the vehicle experienced a high initial impulse, which caused the vehicle to yaw as it progressed into the system, allowing the side of the vehicle to strike the second or third post, resulting in very high occupant impact velocities, penetration of the rail element into the occupant compartment, and/or vehicle rollover. Research efforts to develop a retrofit of existing BCT terminals that could accommodate the 817-kg (1800-lb) car have so far been unsuccessful.

Field modifications that could potentially improve the performance of BCT terminals when impacted by an 817 kg (1800-lb) passenger car were developed by the FHWA and evaluated in a crash test (test no. 471470-7). The performance of the modified BCT terminal was found to be unsatisfactory in the test, with the buckled W-beam intruding into the passenger compartment near the top of the B-pillar on the driver side of the vehicle. One observation from reviewing the photographic coverage of the test was that the end of the terminal and the rail element rose shortly after impact and the vehicle underrode the rail element. This could be partially attributed to the wedge shape of the front end of the vehicle (a 1987 Chevrolet Sprint). However, it is unclear if the impact performance of the modified BCT terminal would have been affected had the vehicle not underridden the end of the terminal and the rail element.

It was then decided by FHWA to retest the modified BCT terminal with an older model Honda Civic so that comparisons could be made with crash tests conducted in previous studies. Also, this would provide an opportunity to assess if the vehicle would again underride the end of the terminal and the rail element and to evaluate the performance of the modified BCT terminal without the underriding phenomenon.

This chapter presents the results and performance evaluation of a modified BCT terminal design when impacted end-on by two different 817-kg (1800-lb) passenger cars. Testing and evaluation were performed according to guidelines outlined in NCHRP Report 230.

7.1 TEST INSTALLATION

The overall test installation consisted of 45.7 m (150 ft) of standard steel strong-post, W-beam (G4(1S)) guardrail with a BCT on the impact end and a standard Texas turned down end treatment on the other end for a total installation length of 64.8 m (212 ft, 6 in). The BCT test installation was first constructed in accordance with the standard BCT design details, as shown in figure 27. After completion of the standard installation, the following field modifications were made to the BCT terminal installation for the first test (test no. 471470-7):

1. The standard line posts at posts 3, 4, and 5 were removed and replaced with breakaway wooden Controlled Release Terminal (CRT) posts. These posts were reinstalled with blockouts, but the rail element was not attached to these posts. This modification allows post 3 through 5 to break away when impacted and facilitates the buckling and bending of the W-beam rail element.

2. The post to rail connection at post 2 was removed. The rail element was then pulled back and a 102-mm (4-in) blockout was placed between the post and the rail element. Again, the rail was not attached to the post. A shelf angle was used to keep the rail in the proper vertical position. This modification increases the flare rate of the rail to facilitate easier buckling and bending of the W-beam rail element. Note that the 102-mm (4-in) blockout was determined empirically by pulling on the rail element until kinking (i.e., slight deformation) of the rail element was observed.

3. A ground strut was added between the foundation tubes for posts 1 and 2. This modification increases the tensile capacity of the anchorage to compensate for any potential loss in tensile capacity caused by not bolting the rail element to posts 2 through 5.

Additional details of the BCT terminal are shown in figure 28. Photographs of the completed installation used in the first test (test no. 471470-7) are shown in figure 29.

It should be noted that posts 3 through 5 were replaced prior to pulling out the rail element at post 2. Thus, the rail element was not directly against posts 3 through 5 (i.e., there were gaps between the rail element and the faces of posts 3 through 5). The widths of the gaps at posts 3, 4, and 5 were 89 mm (3.5 in), 76 mm (3.0 in), and 67 mm (2.6 in), respectively. However, it is believed that the gaps between the rail element and the faces of posts 3 through 5 would have little effect on the impact performance of the terminal for an end-on impact.

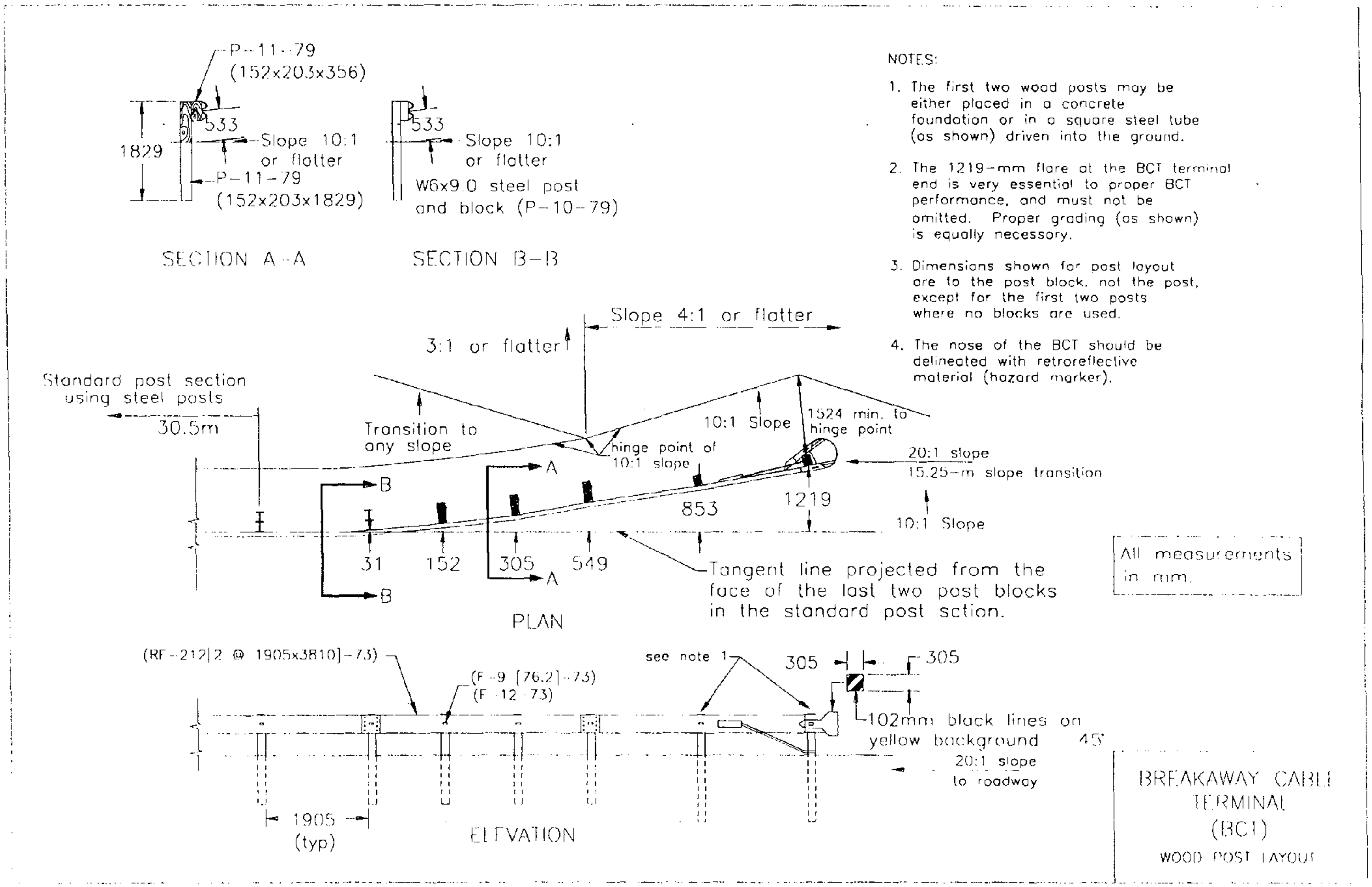


Figure 27. Breakaway cable terminal with CRT posts.

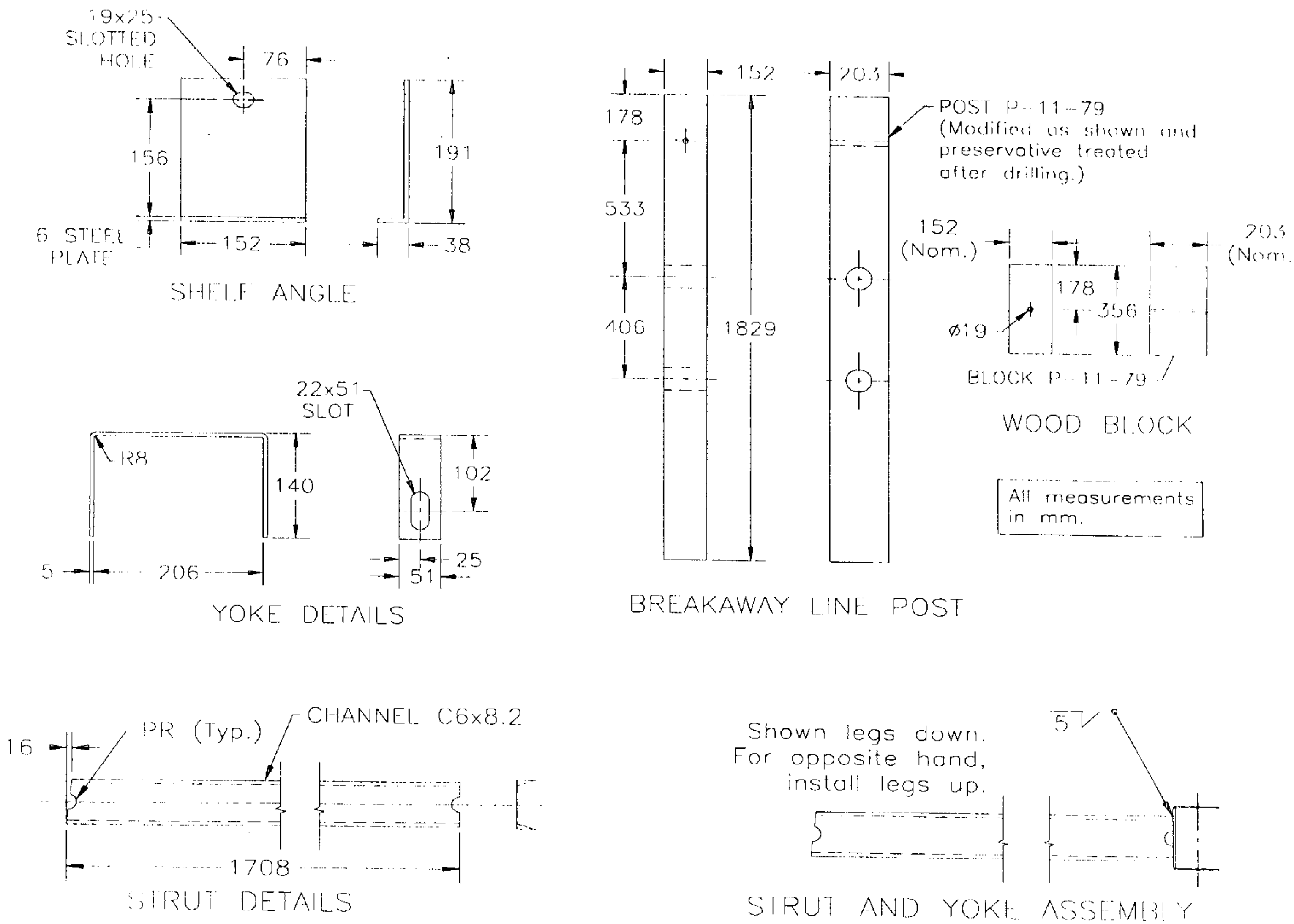


Figure 28. Details of BCT with CRT post.

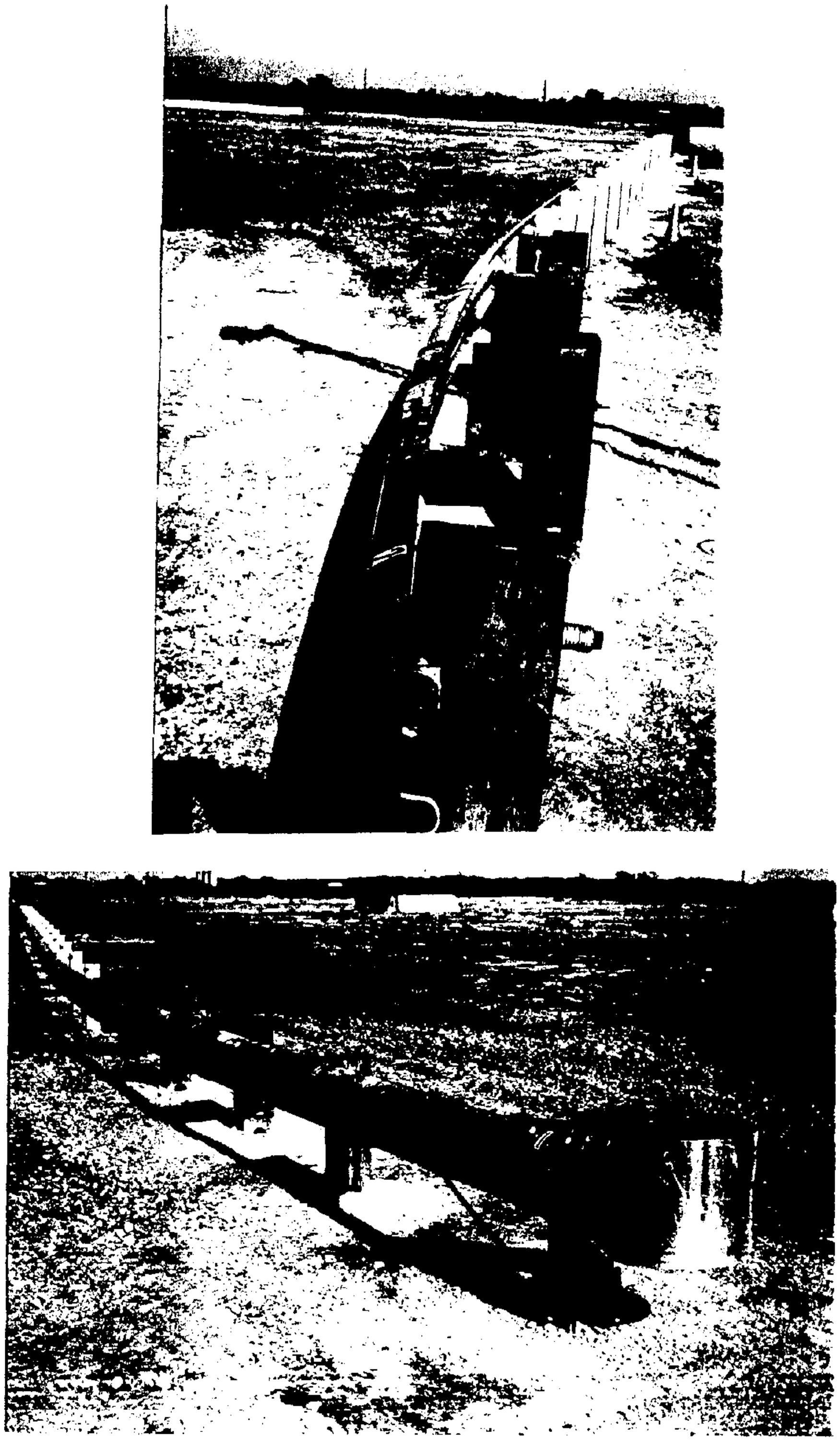


Figure 29. Photographs of test installation 471470-7.

The test installation for the second test (test no. 471470-10) was similar to that used in the first test (test no. 471470-7) except for the following minor changes:

1. The post to rail connections at post 6 were removed to further increase the unsupported length of the W-beam rail element to facilitate buckling of the rail element. (Note that in the previous test, the rail element was detached from the posts at posts 2 through 5, but attached at post 6).

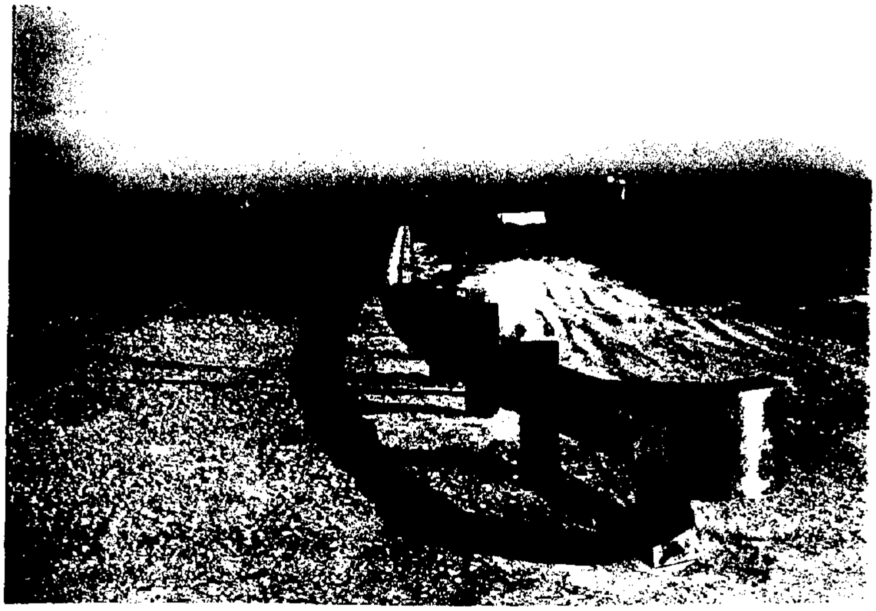
2. Posts 3, 4, and 5 were also removed and replaced with breakaway wooden CRT posts, but these posts were reinstalled with blockouts and positioned such that the rail element was directly against the faces of the blockouts. (Note that in the first test, posts 3 through 5 were replaced prior to pulling back the rail element at post 2. This resulted in gaps between the rail element and the faces of the blockouts at posts 3 through 5). It should be noted that this modification did not totally eliminate the gaps between the rail element and the faces of the blockouts for posts 2 through 5 due to the heads of the bolts used to hold the blockouts to the posts and slight variations in the repositioning of the posts. For example, there were 13-mm- (0.5-in-) wide gaps between the rail element and the faces of the blockouts for posts 4 and 5 in the test installation.

It was noted and marked that there were four kinks in the lower edge of the W-beam rail element as a result of pulling the rail element back 102 mm (4 in) at post 2. These kinks, measured from the centerline of post 1, were at 813 mm (32.0 in), 1435 mm (56.5 in), 2337 mm (92.0 in), and 3226 mm (127.0 in). Photographs of the completed installation used in the second test (test no. 471470-10) are shown in figure 30.

7.2 TEST NUMBER 471470-7 (NCHRP REPORT 230 TEST DESIGNATION 45)

Test vehicle: 1988 Chevrolet Sprint	Impact speed: 99.9 km/h (62.1 mi/h)
Test inertia weight: 817 kg (1800 lb)	Impact angle: 0 degrees
Gross static weight: 894 kg (1970 lb)	

The vehicle impacted the terminal head-on with the centerline of the end post aligned 381 mm (15 in) to the right of the centerline of the vehicle. Upon impact, the end of the terminal began to rise. The vehicle impacted post 1 causing the vehicle to begin yawing in a clockwise rotation, and the end of the terminal section began to buckle. The rail element was pulled off the shelf angle on post 2 and then the rail element began to buckle just past the post 2 location. The vehicle, still yawing clockwise, impacted post 2 and the rail element began to buckle at the post 3 location and move laterally toward the vehicle. As the vehicle impacted post 3, it had ended its clockwise rotation and was sliding at an approximate 23 degree yaw angle. The buckled end of the rail (at post 3 location) impacted the driver's side of the vehicle, tearing a hole in the roof above the B-pillar, and causing the vehicle to begin a counterclockwise rotation. The rail buckled again at the post 5 location. The vehicle



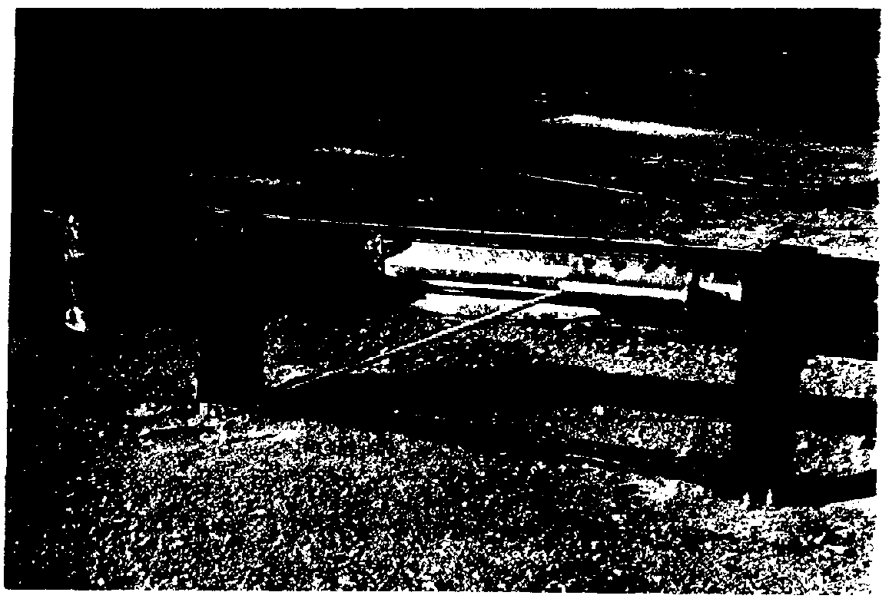


Figure 30. Photographs of test installation 471470-10.

lost contact with the rail element traveling at a speed of 42.8 km/h (26.6 mi/h). As the vehicle cleared the rail, the rear of the vehicle pitched up to approximately 16 degrees. The vehicle completed a counterclockwise spin of almost 270 degrees and came to rest 19.8 m (65 ft) down and 6.1 m (20 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 31.

The BCT terminal received damage up through post 5. The rail element had buckled in several places and posts 1 through 3 broke off at ground level. The vehicle sustained severe damage. A 203-mm (8-in) wide by 305-mm (12-in) deep tear occurred in the roof of the vehicle on the driver's side and the driver's seat belt was cut. The right strut was damaged, the windshield was broken, and the roof and instrument panel were bent. There was damage to the front bumper, hood, grill, radiator, right and left front quarter panel, left door and glass, left rear glass, left rear quarter panel, and the rear bumper, and both doors were jammed. The wheelbase on the right side was shortened from 2.2 m (88.5 in) to 2.1 m (83.5 in). Maximum crush to the vehicle was 330 mm (13.0 in) at the right front corner at bumper height. The left side was crushed 305 mm (12.0 in) at bumper height.

7.3 TEST NUMBER 471470-10 (NCHRP REPORT 230 TEST DESIGNATION 45)

Test vehicle: 1983 Honda Civic	Impact speed: 98.8 km/h (61.4 mi/h)
Test inertia weight: 817 kg (1800 lb)	Impact angle: 0 degrees
Gross static weight: 894 kg (1970 lb)	

The vehicle impacted the BCT terminal head-on with the centerline of the end post aligned 381 mm (15 in) to the right of the centerline of the vehicle. Upon impact, the end of the terminal began to rise. The vehicle impacted post 1, causing the vehicle to begin a very slight yawing in a clockwise rotation. The vehicle impacted post 2, causing the right front wheel to rise and the vehicle to yaw significantly in a clockwise rotation. The rail element began to buckle 430 mm (17 in) upstream from the centerline of the first rail splice (i.e., at post 3). As the vehicle's left front quarter panel impacted post 3, it had ended its clockwise rotation and was sliding at an approximate 20-degree yaw angle. The buckled end of the rail impacted the door on the driver's side of the vehicle, deforming the door into the occupant compartment, pushing the vehicle to the right, and causing the vehicle to begin a counterclockwise rotation. The rail buckled again at 1800 mm (71 in) downstream from the centerline of the first splice. As the buckled end of the rail element continued to push into the vehicle, the rail again buckled at the end of the cable anchor plate and this section of the rail element contacted post 5 and pushed the post laterally. Another section of the rail element contacted post 4, also pushing it laterally. The vehicle lost contact with the buckled end of the rail element traveling at 33.8 km/h (21.0 mi/h) and it continued to yaw, pitch, and roll moderately. The vehicle impacted the rear of the rail at post 12 and rolled back approximately 0.9 m (3 ft) before coming to final rest. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 32.

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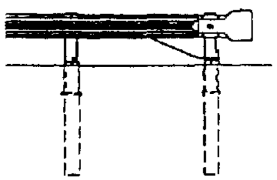
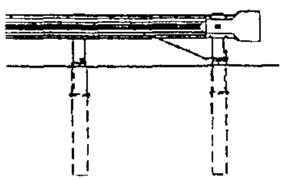


Test No.	7147-7
Date	12/05/91
Test Installation	Breakaway Cable Terminal with CRT Post
Installation Length	46 m (150 ft)
Max. Dynamic Deflection	N/A
Max. Perm. Deformation	7.6 m (25.0 ft)
Test Vehicle	1988 Chevrolet Sprint
Vehicle Weight	
Test Inertia	817 kg (1800 lb)
Gross Static	894 kg (1970 lb)
Vehicle Damage Classification	
VDS	12FD5 & 09LP5
CDC	12FDEW3 & 09LPAN3
Maximum Vehicle Crush	330 mm (13.0 in)

Impact Speed	99.9 km/h (62.1 mi/h)
Impact Angle	0 deg - 381 mm (15 in) offset
Exit Speed	42.8 km/h (26.6 mi/h)
Exit Trajectory	N/A
Vehicle Accelerations (Max. 0.050-s avg)	
Longitudinal	-12.5 g's
Lateral	-3.0 g's
Occupant Impact Velocity at true c.g.	
Longitudinal	8.9 m/s (29.2 ft/s)
Lateral	2.3 m/s (7.6 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-7.8 g's
Lateral	-4.1 g's

Figure 31. Summary of results for test 471470-7.



Test No.	7147-10
Date	02/20/92
Test Installation	Breakaway Cable Terminal with CRT Post
Installation Length	46 m (150 ft)
Max. Dynamic Deflection	N/A
Max. Perm. Deformation	6.4 m (21.0 ft)
Test Vehicle	1983 Honda Civic
Vehicle Weight	
Test Inertia	817 kg (1800 lb)
Gross Static	894 kg (1970 lb)
Vehicle Damage Classification	
VDS	12FD5 & 09LP4
CDC	12FDEW3 & 09LPEN3
Maximum Vehicle Crush	305 mm (12.0 in)

Impact Speed	98.8 km/h (61.4 mi/h)
Impact Angle	0 deg - 381 mm (15 in) offset
Exit Speed	33.8 km/h (21.0 mi/h)
Exit Trajectory	N/A
Vehicle Accelerations (Max. 0.050-s avg)	
Longitudinal	-10.7 g's
Lateral	- 4.5 g's
Occupant Impact Velocity at true c.g.	
Longitudinal	9.6 m/s (31.4 ft/s)
Lateral	3.2 m/s (10.4 ft/s)
Occupant Ridedown Accelerations	
Longitudinal	-8.3 g's
Lateral	-6.3 g's

Figure 32. Summary of results for test 471470-10.

The BCT terminal was damaged up through post 5. The rail element buckled at three different locations: (1) at the end of the cable anchor attachment; (2) 432 mm (17 in) upstream from the centerline of the first splice; and (3) 1803 mm (71 in) downstream from the centerline of the first splice. Posts 1 through 3 broke off at ground level. Posts 1 and 2 split apart upon impact and pieces of the posts were thrown forward and scattered, some as far as 30.5 to 45.7 m (100 to 150 ft) forward of the point of impact. The sheared-off portion of post 3 remained intact and landed against post 4. Posts 4 and 5 had been pushed laterally 38 mm (1.5 in) and 51 mm (2 in), respectively. Also, post 12 was twisted when the vehicle impacted it at the end of the test sequence.

There was 235 mm (9.25 in) permanent deformation into the vehicle driver's side door where the buckled W-beam rail element pushed into the vehicle. The right front strut and sway bar were damaged, the windshield and driver's door glass were broken, and the instrument panel was bent. There was damage to the front bumper, hood, grill, radiator, right and left front quarter panel, left door and glass, and left rear quarter panel. The wheelbase on both sides was shortened 13 mm (0.5 in). Maximum crush to the vehicle was 305 mm (12.0 in) at the right front corner at bumper height.

7.4 SUMMARY OF FINDINGS

Two crash tests were conducted on the field-modified BCT terminal. Both tests involved an 817-kg (1800-lb) passenger car impacting the terminal end-on at a nominal speed of 96.5 km/h (60 mi/h) and 0 degree with the centerline of the vehicle offset 38.1 mm (15 in) from the centerline of the terminal. The performance evaluation of these two crash tests (test nos. 471470-7 and 471470-10) are summarized in tables 17 and 18, respectively.

The field-modified BCT terminal functioned as intended in the first test (test no. 471470-7). After the first post broke away upon impact, the rail element buckled dynamically and bent away to allow the vehicle to pass behind the terminal. However, the buckled rail impacted the driver's side of the vehicle near the top of the B-pillar and penetrated the occupant compartment, tearing a hole in the roof of the vehicle. The vehicle generally remained upright and stable during impact with the BCT terminal. After exiting the test installation, the vehicle experienced some moderate pitching and yawing. The vehicle sustained extensive damage with considerable deformation and intrusion into the passenger compartment (i.e., the rail had torn a hole in the roof on the driver's side and cut the seat belt). The trajectory of the vehicle was judged not to pose any potential hazard to adjacent traffic as the vehicle came to rest behind the installation. The occupant impact velocities and ridedown accelerations were within the acceptable limits as outlined in NCHRP Report 230 guidelines.

The impact performance of the field-modified BCT terminal was judged unsatisfactory for this first test. Part of the rail element penetrated the occupant compartment, showing potential for extreme hazard to occupants of the vehicle.

Table 17. Assessment of results of test 471470-7 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute — Test No.: 471470-7 — Test Date: 12/05/91

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The modified BCT allowed controlled penetration by the vehicle.	Pass
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.	The buckled rail element penetrated the passenger compartment, presenting undue hazard to occupants of the vehicle.	Fail
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 although there was some pitching after exiting from the installation. There was deformation and intrusion into the occupant compartment.	Fail
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 Occupant Impact Velocity = 8.9 m/s (29.2 ft/s) Lateral Occupant Impact Velocity = 2.3 m/s (7.6 ft/s)	Pass
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 Ridedown Acceleration = -7.8 g's Lateral Ridedown Acceleration = -4.1 g's	Pass
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 20 m (65 ft) downstream and 6 m (20 ft) behind the point of impact.	Pass
J. Vehicle trajectory behind the test article is acceptable.	Vehicle came to rest behind the BCT	Pass

Table 18. Assessment of results of test 471470-10 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-10 | Test Date: 02/20/92

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The modified BCT allowed controlled penetration by the vehicle.	Pass
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.	The buckled rail element deformed the passenger compartment, presenting undue hazard to occupants of the vehicle, and debris was thrown a considerable distance forward of the vehicle.	Fail
<u>Occupant Risk</u>		
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 although there was some pitching and yawing after exiting from the installation. There was deformation and intrusion into the occupant compartment.	Fail
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 Occupant Impact Velocity = 9.6 m/s (31.4 ft/s) Lateral Occupant Impact Velocity = 3.2 m/s (10.4 ft/s)	Pass
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 Ridedown Acceleration = -8.3 g's Lateral Ridedown Acceleration = -6.3 g's	Pass
<u>Vehicle Trajectory</u>		
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 21 m (69 ft) downstream and 1 m (3 ft) behind the point of impact.	Pass
J. Vehicle trajectory behind the test article is acceptable.	Vehicle came to rest behind the BCT	Pass

One observation from reviewing the photographic coverage of the test was that the end of the terminal and the rail element rose shortly after impact and the vehicle underrode the rail element. This could be partially attributed to the wedge shape of the front end of the vehicle (a 1987 Chevrolet Sprint). However, it is unclear if the impact performance of the field-modified BCT terminal would have been affected had the vehicle not underridden the end of the terminal and the rail element.

It was then decided by FHWA to retest the field-modified BCT terminal with an older model Honda Civic so that comparisons could be made with crash tests conducted in previous studies. This would provide an opportunity to assess if the vehicle would again underride the end of the terminal and the rail element and to evaluate the performance of the modified BCT terminal without the underriding phenomenon. Also, some additional field modifications were incorporated into the terminal design.

In the second test (test no. 471470-10), the field-modified BCT terminal also functioned as intended with the older model Honda Civic. After the first post broke away upon impact, the rail element buckled dynamically and bent away to allow the vehicle to pass behind the guardrail. However, the buckled rail impacted the driver's side of the vehicle, deforming the door 235 mm (9.25 in) into the occupant compartment. Debris from the first two posts was thrown a considerable distance forward of the vehicle. The vehicle generally remained upright and stable during the impact with the BCT terminal. However, after exiting the test installation, the vehicle experienced some moderate pitching and yawing.

The vehicle sustained extensive damage with considerable deformation into the passenger compartment. The trajectory of the vehicle was judged not to pose any potential hazard to adjacent traffic as the vehicle came to rest behind the installation. The longitudinal occupant impact velocity of 9.6 m/s (31.4 ft/s) was higher than the NCHRP Report 230 design limit of 9.1 m/s (30 ft/s), but met the recommended limit of 12.2 m/s (40 ft/s). The lateral occupant impact velocity and both ridedown accelerations were within the acceptable limits, as outlined in NCHRP Report 230 guidelines.

The impact performance of the modified BCT end treatment was also judged to be unsatisfactory in this second test. The buckled rail element impacted the door on the driver side of the vehicle, deforming the occupant compartment considerably and showing potential for hazard to occupants of the vehicle.

In summary, the performance of the field-modified BCT terminal in both small car end-on tests appeared to be somewhat better than that of the standard BCT design in similar crash tests. The rail element appeared to buckle more readily, but the problem remained in which the rail element impacted the side of the vehicle as the vehicle rotated into the buckled rail. The buckled rail penetrated the occupant compartment in one test and significantly deformed the occupant compartment in the other test. Thus, the performance of the field-modified BCT terminal was judged to be unsatisfactory for both small car end-on tests.

VIII. MINNESOTA SWING-AWAY MAILBOX SUPPORT

The Minnesota Department of Transportation (MnDOT) has designed a swing-away mailbox support for use in locales where snow and ice removal during the winter time presents a problem. The Minnesota swing-way mailbox support design utilizes a cantilevered arm for attachment of the mailbox assembly. The cantilever design is intended to allow for snowplowing operation beyond the shoulder or curbline, thus reducing snowdrifting on the roadway and minimizing the potential for damaging the mailbox support, which could present a maintenance problem. It is easily installed using existing highway agency equipment, can be salvaged and reinstalled, and costs considerably less than current mailbox designs approved by MnDOT.

This chapter presents the results of four full-scale crash tests conducted on this Minnesota swing-away mailbox support and the evaluation of its impact performance. Testing and evaluation was performed in accordance with guidelines outlined in NCHRP Report 350 and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.*[(6)]

8.1 TEST INSTALLATION

The Minnesota swing-away mailbox support, a schematic diagram of which is shown in figure 33, consists of four major components:

- U-channel base post,
- Vertical support,
- Cantilever arm, and
- Mailbox assembly.

A 2.13-m- (7-ft-) long, 4.46-kg/m (3-lb/ft) U-channel sign post is driven into the ground as a base post, leaving a stub height of approximately 0.46 m (18 in) above ground level. The minimum specified embedment depth of the post is 1.22 m (4 ft) so that either a 1.83-m- (6-ft-) or a 2.13-m- (7-ft-) long post may be used with the installation. A post length of 2.13 m (7 ft) was used in the crash tests since it was considered to be a more critical condition from a base bending standpoint. Note that the strong axis of the U-channel post is aligned with the direction of vehicle travel.

A vertical support, made from 42.2-mm- (1.66-in-) outside diameter, 35-mm- (1.38-in-) inside diameter standard-weight pipe, is bolted to the post stub with two 9.5 mm x 63.5 mm (3/8 in x 2.5 in) grade 5 bolts. The two bolts are spaced 0.31 m (12 in) apart with the bottom bolt located 102 mm (4 in) above ground level. The top 0.31 m (12 in) of the pipe is bent at a 45-degree angle. A 0.41-m- (16-in-) long, 33.4-mm- (1.315-in-) outside diameter, 26.6-mm- (1.049-in-) inside diameter standard-weight pipe is inserted into the bent end of the

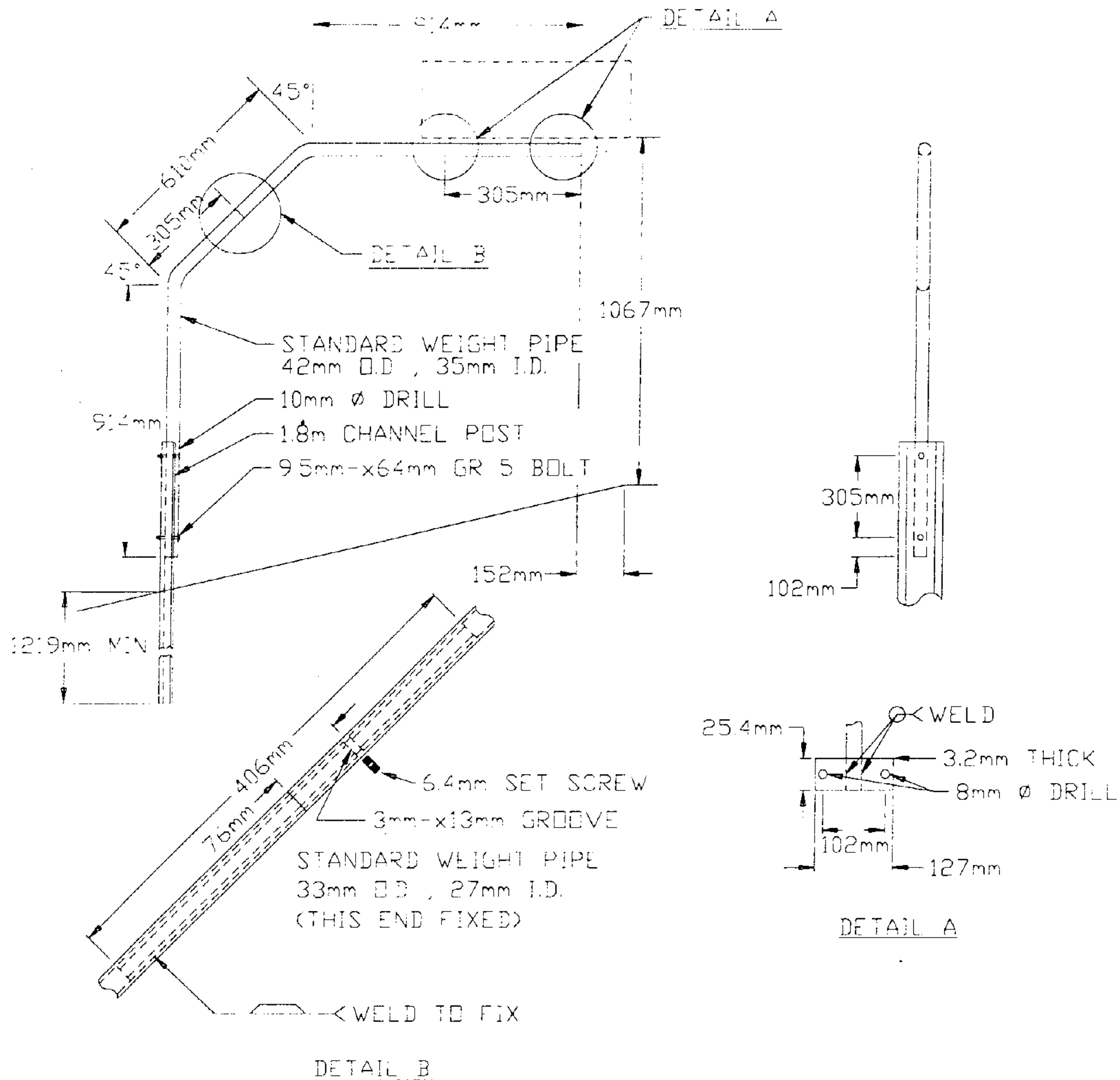


Figure 33. Minnesota swing-away mailbox support design.

vertical support and welded in place. The insert pipe extends 203 mm (8 in) beyond the end of the vertical support for attachment of the cantilever arm. A groove, 12.7-mm (1/2-in) wide and 3.2-mm (1/8-in) deep, is cut into the insert pipe 76.2 mm (3 in) above the end of the vertical support for use with a 6.4-mm- (1/4-in-) diameter set screw to attach the cantilever arm. The set screw and groove configuration renders removal of the cantilever arm more difficult so as to discourage vandalism. The set screw still allows the cantilever arm to rotate freely about the insert pipe and to separate readily from the vertical support upon impact and is not expected to have any appreciable effect on the impact performance of the support.

A cantilever arm, also made from 42.2-mm- (1.66-in-) outside diameter, 35-mm- (1.38-in-) inside diameter standard-weight pipe, connects the vertical support to the mailbox assembly. The cantilever arm is 1.22 m (48 in) in length, 0.31 m (12 in) of which is bent at 45 degrees for attachment to the insert pipe. Two 3.2-mm- (1/8-in-) thick, 127-mm- (5-in-) long, 25.4-mm- (1-in-) wide metal straps, one at the end of the cantilever arm and the other spaced 0.31 m (12 in) apart, are welded to the top of the pipe. Two 7.9-mm (5/16-in) holes, spaced 102 mm (4 in) center to center, are drilled on the straps for attachment of the mailbox assembly to the cantilever arm.

A 0.41-m- (16-in-) long, 0.20-m- (8-in-) wide (nominal), 25.4-mm- (1-in-) thick (nominal) wood board is bolted to the straps on the cantilever arm with four 6.35-mm- (1/4-in-) diameter, 38.1-mm- (1.5-in-) long carriage bolts. A size 1-A standard mailbox is attached to the wood board with sheetrock (drywall) screws.

A standard plastic newspaper tube is also attached to one side of the mailbox assembly using a 16-gauge metal bracket. The plastic newspaper tube is attached to the metal bracket using two 6.35-mm x 12.7-mm (1/4-in x 1/2 in) bolts and the metal bracket is attached to the bottom of the wood board with four 25.4-mm- (1-in-) long sheetrock (drywall) screws. Note that the plastic newspaper tube is approved by the U. S. Postal Service for attachment to either side of the mailbox assembly. For the test installations, the plastic newspaper tubes were installed on the nonimpact side of the mailbox assemblies to allow direct contact of the mailbox with the windshield of the vehicle. However, given the light weight and crushable nature of the plastic newspaper tube and the attachment hardware, the positioning of the plastic newspaper tube is not expected to have any appreciable effect on the impact performance of the mailbox installation.

For the triple mailbox assembly, the cantilever arm consists of standard weight pipe for the bent portion of the arm that attaches to the insert arm and the first 127 mm (5 in) of the horizontal arm. The remainder of the horizontal arm is constructed of thin-wall pipe (such as muffler pipe) welded to the standard weight pipe to reduce the weight of the cantilever arm. The horizontal arm forks out into three branches, spaced 0.31 m (12 in) apart, one for each of the three mailbox assemblies. The attachment of the mailboxes to the cantilever arm was similar to that of the single mailbox assembly. For each mailbox assembly, a wood board was bolted to the cantilever arm, and the mailbox was attached to the wood board with sheetrock (drywall) screws. A single plastic newspaper tube was attached to one end (nonimpact end) of the triple mailbox assembly.

Photographs of the test installation with a single mailbox assembly and triple mailbox assembly are shown in figures 34 and 35, respectively.

8.2 TEST NUMBER 471470-11 (NCHRP REPORT 350 TEST DESIGNATION 3-60)

Test vehicle: 1986 Yugo GV Test inertia weight: 820 kg (1808 lb) Gross static weight: 895 kg (1971 lb)	Impact speed: 35.1 km/h (21.8 mi/h) Impact angle: 0 degrees

The vehicle impacted the mailbox support with the support aligned with the right front quarter point of the vehicle. Upon impact, the vertical support and the U-channel base post began to lean forward and the cantilever arm and mailbox assembly began to rotate toward the vehicle. The cantilever arm and mailbox assembly rotated 90 degrees and the cantilever arm separated from the vertical support. Traveling at a speed of 25.9 km/h (16.1 mi/h), the vehicle lost contact with the cantilever arm and mailbox assembly. However, the vertical support remained in contact with the undercarriage of the vehicle until the vehicle had slowed to a speed of 24.8 km/h (15.4 mi/h). Brakes on the vehicle were applied after the vehicle exited the test site. The vehicle subsequently came to rest approximately 24 m (80 ft) downstream from the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 36.

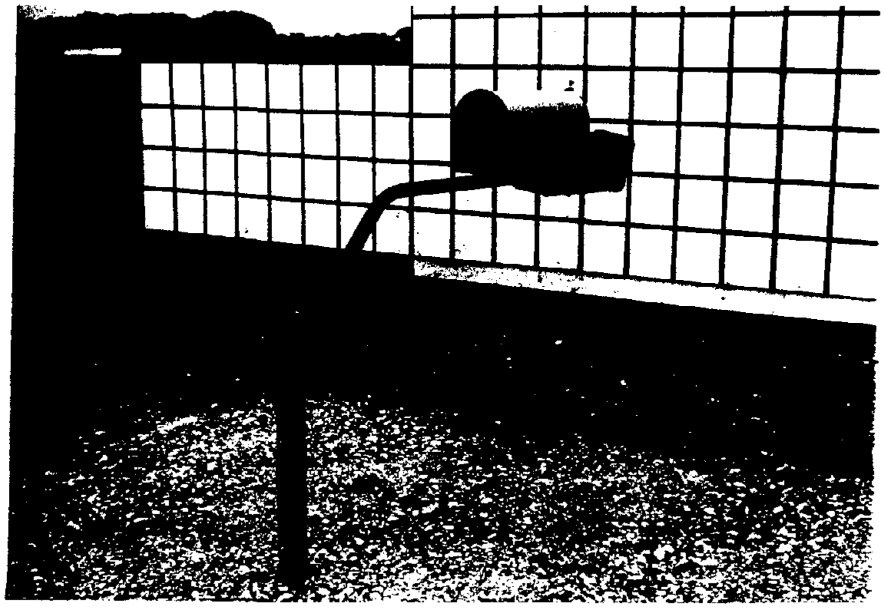
The cantilever arm and mailbox assembly came to rest approximately 17 m (55 ft) downstream and 5 m (15 ft) to the right of the impact point. The cantilever arm was only scraped and the mailbox assembly was deformed. The vertical support was scraped and the U-channel base post was bent and pushed back 180 mm (7 in) at ground level.

There was 80 mm (3.2 in) permanent deformation to the vehicle bumper where contact with the vertical support and U-channel base post occurred. There were dents in the oil pan and gas tank and scrape marks along the floor pan on the right side caused by contact with the vertical support of the mailbox test installation.

8.3 TEST NUMBER 471470-12 (NCHRP REPORT 350 TEST DESIGNATION 3-61)

Test vehicle: 1986 Yugo GV Test inertia weight: 820 kg (1808 lb) Gross static weight: 895 kg (1971 lb)	Impact speed: 104.9 km/h (65.2 mi/h) Impact angle: 0 degrees

The vehicle impacted the mailbox vertical support with the mailbox support aligned with the right front quarter point of the vehicle. Upon impact, the vertical support and the U-channel base post began to lean forward and the cantilever arm and mailbox assembly began to rotate toward the vehicle. At this time, the mailbox also began to separate from the wood board that was attached to the cantilever arm. The mailbox became completely detached from the wood board, and the mailbox contacted the A-pillar on the driver's side of



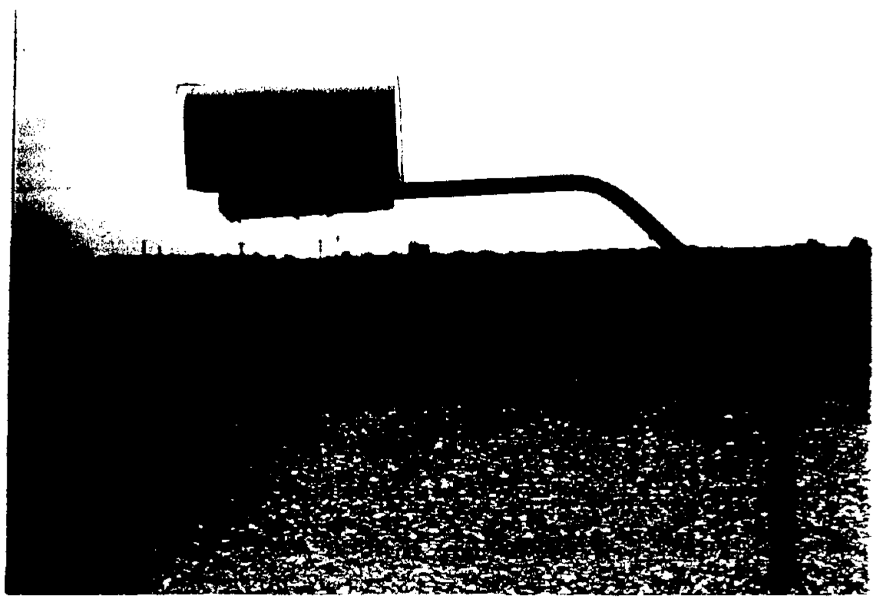
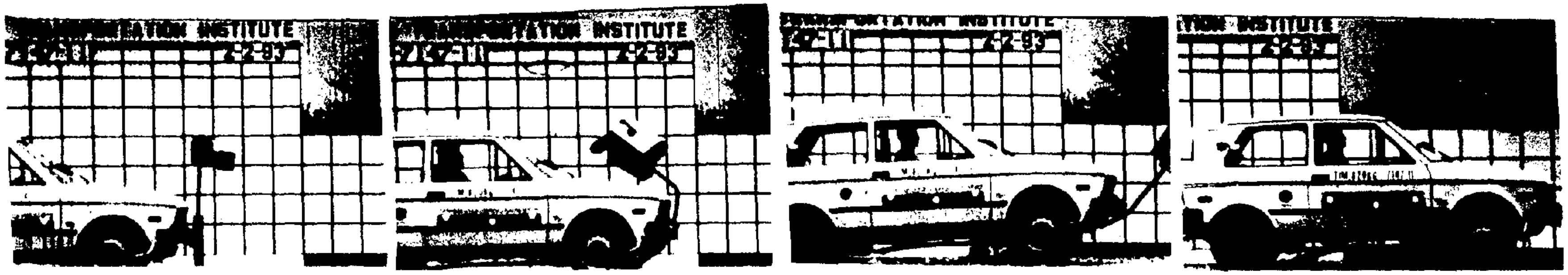


Figure 34. Test installation with single mailbox assembly.

Figure 35. Test installation with triple mailbox assembly.



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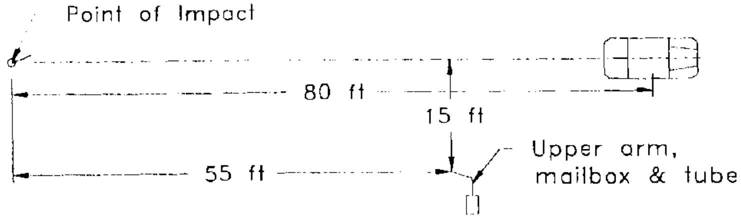
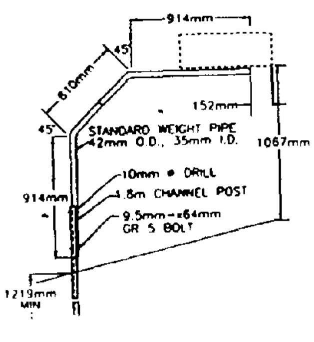




Test No.	7147-11
Date	02/02/93
Test Installation	Minnesota Swing-Away Mailbox
Mounting Height	1016 mm (40 in)
Installation Depth	1575 mm (62 in) Driven
Soil Type	Strong Soil (S-1)
Test Vehicle	1986 Yugo GV
Vehicle Weight	
Test Inertia	820 kg (1806 lb)
Gross Static	895 kg (1971 lb)
Vehicle Damage Classification	
TAD	12FR1
CDC	12FREN1
Maximum Vehicle Crush	80 mm (3.2 in)

Impact Speed	35.1 km/h (21.8 mi/h)
Impact Angle	0 deg-381 mm (15 in) Offset
Exit Speed	25.9 km/h (16.1 mi/h)
Change in Velocity	9.2 km/h (5.7 mi/h)
Change in Momentum	2086 N-s (469 lb-s)
Vehicle Accelerations (Max. 0.050-s avg)	
Longitudinal	-1.6 g's
Lateral	0.4 g's
Occupant Impact Velocity	
Longitudinal	1.9 m/s (6.1 ft/s)
Lateral	No Contact
Occupant Ridedown Accelerations	
Longitudinal	0.9 g's
Lateral	N/A

Figure 36. Summary of results for test 471470-11.

the vehicle. The mailbox lost contact with the vehicle while the vehicle was traveling at 98.0 km/h (60.9 mi/h). The vertical support and U-channel base post remained in contact with the undercarriage of the vehicle until the vehicle had slowed to a speed of 97.3 km/h (60.5 mi/h). Brakes on the vehicle were applied at 1.2 s after impact and the vehicle subsequently came to rest 134 m (441 ft) downstream from the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 37.

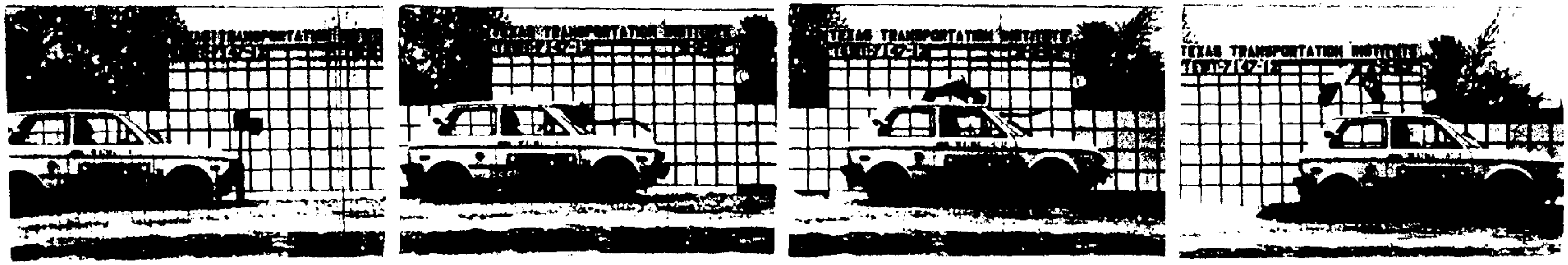
The mailbox installation separated into several pieces. The plastic newspaper tube landed 15 m (48 ft) downstream and 8 m (25 ft) to the left of the point of impact. The deformed mailbox landed 18 m (60 ft) downstream and 5 m (18 ft) to the left of point of impact. The cantilever arm and wood board were found 22 m (72 ft) downstream and 12 m (38 ft) to the left of the point of impact. The vertical support arm was only scraped and the U-channel base post was bent and pushed back 150 mm (6 in) at ground level.

There was 120 mm (4.7 in) permanent deformation to the vehicle bumper where contact with the vertical support and the U-channel base post occurred. The A-pillar on the driver's side was deformed from impact by the mailbox and the windshield was cracked around the point of impact. The door post on the driver side was bent and the glass broken out. There was also damage to the hood and grill and the right rear tire and rim. There was a dent in the gas tank, and scrape marks and a dent along the floor pan on the right side of the undercarriage caused by contact with the vertical support.

8.4 TEST NUMBER 471470-13 (NCHRP REPORT 350 TEST DESIGNATION 3-61)

Test vehicle: 1986 Yugo GV	Impact speed: 103 km/h (64.0 mi/h)
Test inertia weight: 820 kg (1808 lb)	Impact angle: 0 degrees
Gross static weight: 895 kg (1971 lb)	

The vehicle impacted the mailbox assembly with the centerline of the mailbox assembly aligned with the centerline of the vehicle. Upon impact, the mailbox shattered the windshield. The cantilever arm contacted the A-pillar on the passenger's side of the vehicle and the mailbox assembly started to rotate away from the windshield. The cantilever arm and mailbox assembly separated from the vertical support. The mailbox assembly and the cantilever arm then went up and over the vehicle. Loss of contact between the mailbox assembly and vehicle occurred as the vehicle was traveling at 99.6 km/h (61.9 mi/h). The windshield, which was held in place by a rubber grommet, separated from the vehicle. The detached windshield first went outward and upward. The detached windshield contacted the roof of the vehicle and was partially on the roof of the vehicle before eventually sliding back inside the occupant compartment. The brakes on the vehicle were applied and the vehicle subsequently came to rest 100 m (327 ft) downstream from the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 38.



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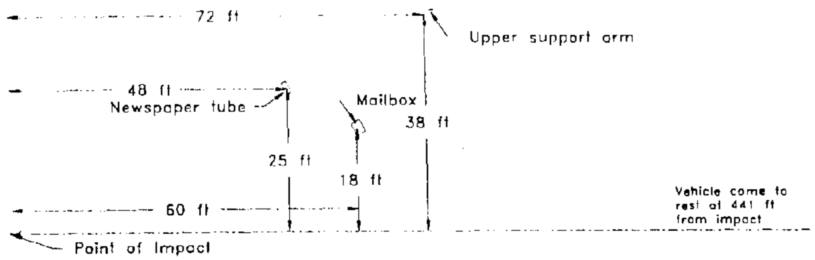
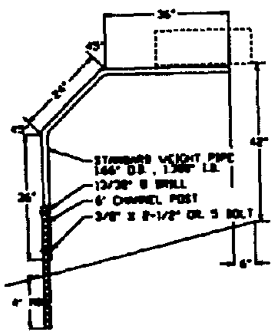
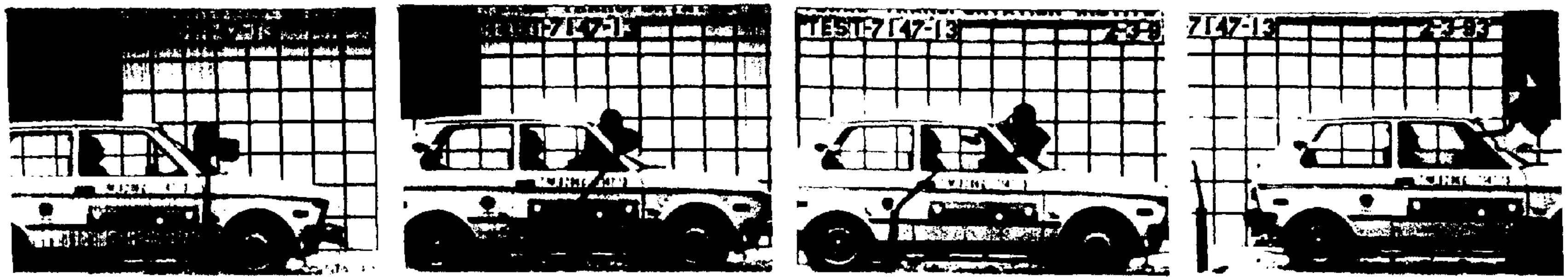




Test No.	7147-12	Impact Speed	104.9 km/h (65.2 mi/h)
Date	02/02/93	Impact Angle	**0 deg-381 mm (15 in) Offset**
Test Installation	Minnesota Swing-Away Mailbox	Exit Speed	98.0 km/h (60.9 mi/h)
		Change in Velocity	6.9 km/h (4.3 mi/h)
Mounting Height	1016 mm (40 in)	Change in Momentum	1573 N-s (354 lb-s)
Installation Depth	**1575 mm (62 in) Driven**	Vehicle Accelerations	
Soil Type	Strong Soil (S-1)	(Max. 0.050-s avg)	
Test Vehicle	1986 Yugo GV	Longitudinal	-1.9 g's
Vehicle Weight		Lateral	1.0 g's
Test Inertia	820 kg (1806 lb)	Occupant Impact Velocity	
Gross Static	895 kg (1971 lb)	Longitudinal	1.3 m/s (4.3 ft/s)
Vehicle Damage Classification		Lateral	1.4 m/s (4.5 ft/s)
TAD	12FR1	Occupant Ridedown Accelerations	
CDC	12FREN1 & 12FLGN6	Longitudinal	-2.7 g's
Maximum Vehicle Crush	120 mm (4.7 in)	Lateral	4.6 g's

Figure 37. Summary of results for test 471470-12.



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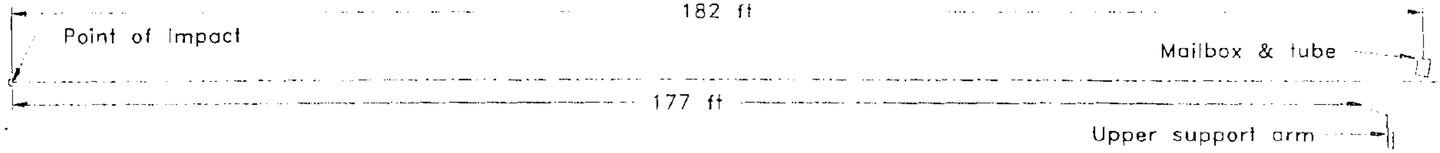
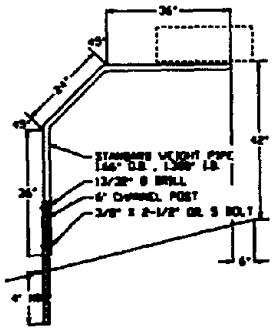


Vehicle came to rest 327 ft down from point of impact



Test No.	7147-13	Impact Speed	103.0 km/h (64.0 mi/h)
Date	02/03/93	Impact Angle	0 deg-offset to Impact Box
Test Installation	Minnesota Swing-Away Mailbox	Exit Speed	99.6 km/h (61.9 mi/h)
		Change in Velocity	3.4 km/h (2.1 mi/h)
Mounting Height	1016 mm (40 in)	Change in Momentum	768 N-s (172 lb-s)
Installation Depth	1575 mm (62 in) Driven	Vehicle Accelerations (Max. 0.050-s avg)	
Soil Type	Strong Soil (S-1)		
Test Vehicle	1986 Yugo GV	Longitudinal	-1.0 g's
Vehicle Weight		Lateral	0.5 g's
Test Inertia	820 kg (1806 lb)	Occupant Impact Velocity	
Gross Static	895 kg (1971 lb)	Longitudinal	No Contact
Vehicle Damage Classification		Lateral	1.2 m/s (3.9 ft/s)
TAD	None Applicable	Occupant Ridedown Accelerations	
CDC	12FRGN6	Longitudinal	N/A
Maximum Vehicle Crush	Penetrated Windshield	Lateral	1.0 g's

Figure 38. Summary of results for test 471470-13.

The mailbox installation separated into several pieces. The cantilever arm and part of the wood board landed 54 m (177 ft) downstream and 1.4 m (4.5 ft) to the right of the point of impact. The severely deformed mailbox, part of the wood board, and plastic newspaper tube came to rest 55 m (182 ft) downstream and 0.3 m (1 ft) to the left of the point of impact. The vertical support was only scraped and the U-channel base post was not damaged or pushed back.

There was 30-mm (1.2-in) permanent deformation to the A-pillar on the passenger's side of the vehicle, and the door post on the passenger's side was deformed at the location where the cantilever arm made contact. The windshield was broken out and lying on the floorboard of the vehicle. However, it should be noted that the windshield actually went outward and upward after separation from the vehicle and was partially on the roof of the vehicle before falling back into the occupant compartment. There was also a scratch located on the left rear section of the roof from contact by the detached cantilever arm as it went over the vehicle.

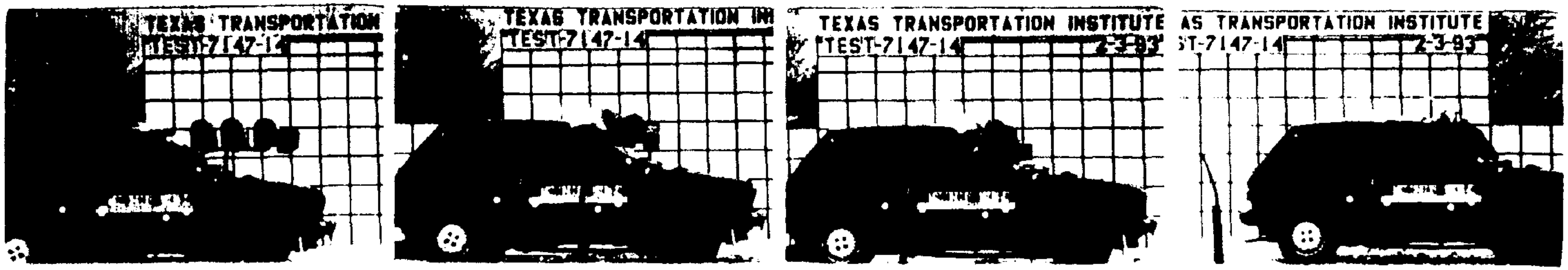
8.5 TEST NUMBER 471470-14 (NCHRP REPORT 350 TEST DESIGNATION 3-61)

Test vehicle: 1989 Yugo GVL	Impact speed: 101.0 km/h (62.8 mi/h)
Test inertia weight: 820 kg (1806 lb)	Impact angle: 0 degrees
Gross static weight: 895 kg (1971 lb)	

The vehicle impacted the triple mailbox assemblies with the centerline of the mailbox assembly aligned with the centerline of the vehicle. Upon impact, the mailbox assemblies shattered the windshield and the first mailbox assembly bounced up and contacted the edge of the roof just above the windshield. The cantilever arm contacted the A-pillar on the passenger's side of the vehicle and the cantilever arm and mailbox assemblies separated from the vertical support. The cantilever arm and mailbox assemblies intruded into the occupant compartment of the vehicle and rode along partially in the compartment and partially on the hood of the vehicle. Brakes on the vehicle were applied and the vehicle subsequently came to rest 121 m (397 ft) downstream from the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 39.

The mailbox assemblies were deformed but remained attached to the cantilever arm, and remained with the vehicle through final rest. The vertical support was only scraped and the U-channel base post was bent slightly.

The vehicle sustained damage around the windshield area and in the occupant compartment. The mailbox assemblies intruded into the occupant compartment through the windshield and remained partially in the compartment throughout the test period. The roof of the vehicle was deformed upward from inside the vehicle approximately 50 mm (2 in). The passenger's side door was pushed out 40 mm (1.6 in) and the glass was shattered. The A-pillar and door post on the passenger's side were also deformed. The windshield was inside the vehicle.



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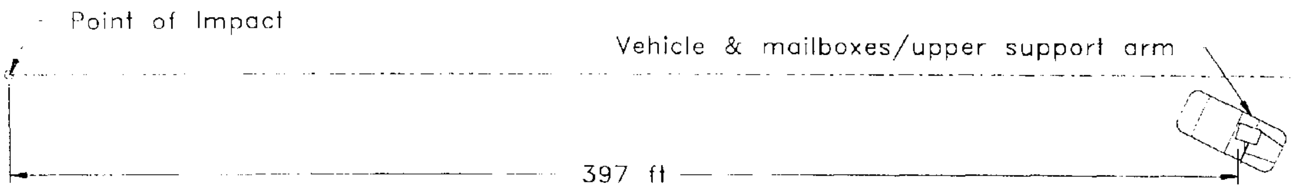
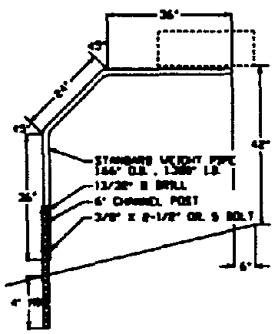




Test No.	7147-14
Date	02/03/93
Test Installation	Minnesota Swing-Away Mailbox
Mounting Height	1016 mm (40 in)
Installation Depth	1575 mm (62 in) Driven
Soil Type	Strong Soil (S-1)
Test Vehicle	1989 Yugo GV
Vehicle Weight	
Test Inertia	820 kg (1806 lb)
Gross Static	895 kg (1971 lb)
Vehicle Damage Classification	
TAD	None Applicable
CDC	12FRGN7
Maximum Vehicle Crush	Penetrated Windshield

Impact Speed	101.0 km/h (62.8 mi/h)
Impact Angle	0 deg-Offset to Impact Box
Exit Speed	Remained in and on Vehicle
Change in Velocity	N/A
Change in Momentum	N/A
Vehicle Accelerations (Max. 0.050-s avg)	
Longitudinal	-1.3 g's
Lateral	-0.3 g's
Occupant Impact Velocity	
Longitudinal	0.9 m/s (2.8 ft/s)
Lateral	No Contact
Occupant Ridedown Accelerations	
Longitudinal	-0.3 g's
Lateral	N/A

Figure 39. Summary of results for test 471470-14.

8.6 SUMMARY OF FINDINGS

The first two crash tests (test nos. 471470-11 and 471470-12) involving impacts with the vertical supports of the mailbox installations with single mailbox assemblies showed occupant impact velocities and ridedown accelerations that were well below the limiting values of 4.57 m/s (15 ft/s) and 20 g's, respectively. There was no penetration or intrusion into the occupant compartment. Debris from the test installation, which consisted of the cantilever arm and the mailbox assembly, remained close to the approximate path of the vehicle and did not pose any potential hazard to adjacent traffic. The vehicle remained stable during and after the impact sequence.

The third crash test (test no. 471470-13) with the single mailbox assembly directly impacting the windshield resulted in a shattered and cracked windshield, but the windshield managed to keep the mailbox assembly from intruding or penetrating into the occupant compartment. Damage to the windshield is normally not considered a desirable behavior since it could obstruct the driver's vision or otherwise cause the driver to lose control of the vehicle. However, given the need for a cantilever design because of snowplowing operations, damage to the windshield is considered an acceptable tradeoff provided that there was no intrusion or penetration into the occupant compartment.

The fourth crash test (test no. 471470-14) with triple mailbox assemblies was judged to have failed the evaluation criteria set forth in NCHRP Report 350. The mailbox assemblies shattered the windshield and substantially intruded and penetrated into the occupant compartment, which was judged as unacceptable. It appeared that two factors contributed to the unsatisfactory performance: (1) the combined weight of the triple mailbox assemblies and the cantilever arm was 19 kg (42 lb), which was more than double the weight of 8.8 kg (19.5 lb) for the single mailbox assembly, and (2) the width of the triple mailbox assemblies allowed the mailbox assemblies to impact and penetrate the windshield prior to the cantilever arm impacting the A-pillar of the vehicle, which would have partially counteracted against the force of the mailbox assemblies into the windshield.

In summary, the Minnesota swing-away mailbox support with a single mailbox assembly was judged to have successfully met all evaluation criteria set forth in NCHRP Report 350 and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals.*

The following recommendations are proposed for consideration in order to improve the safety performance of the mailbox support design:

- The cantilever design allows the mailbox assembly to come into direct contact with the windshield of the vehicle without the front of the vehicle contacting the vertical support. While the crash test results indicate that a single box assembly performed satisfactorily without penetrating the windshield and intruding into the occupant compartment, it did shatter and crack the windshield. It would be desirable to keep the combined weight of the mailbox assembly and the cantilever arm to a minimum.

- Attachments to the cantilever arm and mailbox assembly, such as a plastic newspaper tube or a crushable light-gauge metal rural fire number or address plate, should be of such construction and location that they will not contribute to the potential of fracturing the windshield or intruding into the passenger compartment. The test installation had a plastic newspaper tube attached to the mailbox assembly and its presence did not appear to adversely affect the safety performance of the mailbox assembly and support.

- Another consideration is the size of the mailbox itself. There are three commonly used sizes for mailboxes: 1, 1-A and 2. The crash tests were conducted with the size 1-A mailbox, which is 0.53 m (21 in) long, 0.25 m (10 in) high, and 0.20 m (8 in) wide and weighs approximately 2.5 kg (5.5 lb). The smaller size 1 mailbox is 0.48 m (19 in) long, 0.23 m (9 in) high, and 0.16 m (6-1/4 in) wide and weighs approximately 1.6 kg (3.5 lb). The larger size 2 mailbox is 0.60 m (23.5 in) long, 0.38 m (15 in) high, and 0.28 m (11 in) wide and weighs approximately 4.5 kg (10 lb). The smaller and lighter size 1 mailbox should work well with the support. However, there are insufficient data at this time to determine how well the larger and heavier size 2 mailbox would work with the support.

- Because of the unsatisfactory performance of the triple mailbox assemblies, use of the swing-away mailbox support design should be limited to only a single mailbox assembly. In situations where multiple mailboxes are to be installed at the same location, each mailbox assembly should be installed on its own support and not multiple mailbox assemblies on a single support. Also, having the mailbox installations spaced far enough apart to separate out the effects of individual impacts may be desirable. Based on the time between initial impact and separation of the cantilever arm and mailbox assembly from the vertical support, a spacing of roughly 1.07 m (3.5 ft) between installations is suggested. However, it should be noted that this suggestion is based on limited information and engineering judgment.

IX. SINGLE SLOPE BRIDGE RAIL

A single slope concrete median barrier was previously designed, developed, and successfully crash tested at the Texas Transportation Institute (TTI) in accordance with guidelines set forth in NCHRP Report 230.[1] The barrier was approved by FHWA and adopted by many States for field applications. As implied by its name, this single slope barrier has a single sloped face at 79 degrees (or 11 degrees to the vertical) and is 1.07 m (42 in) high. The single slope barrier has several advantages over the New Jersey safety-shaped barrier. First, the single slope barrier has a lower propensity for rollover than the New Jersey safety-shaped barrier without greatly increasing the damage and lateral acceleration to impacting vehicles.

Second, while the initial construction cost of the single slope barrier is comparable to that of the standard safety-shaped barrier, the maintenance cost and life-cycle costs of the single slope barrier should be substantially lower. To maintain the shape and height of the barrier for the standard safety-shaped barrier, the pavement surface has to be first lowered before any overlay can be applied to provide a new wearing surface. This is an expensive outlay over the life of the pavement and the barrier. On the other hand, a single slope barrier can accommodate overlays without any concern for the shape of the barrier. Also, with an initial height of 1.07 m (42 in), the barrier can accommodate up to 254 mm (10 in) of overlay, e.g., five overlays of 51 mm (2 in) each over the years, and still has a height of 0.81 m (32 in), which is the height of the standard New Jersey safety-shaped barrier.

Third, the single slope barrier can be advantageous in situations where there are differences in elevation between the two sides of divided highways, such as at superelevated curves. Since there is only a single sloped face, the height of the barrier can be different on the two faces to accommodate the difference in elevation without concern over the shape of the barrier. This can simplify the construction of the barrier, especially when slip-forming is used.

The Washington State Department of Transportation (WaDOT) is interested in adapting this single slope barrier design for use as a bridge rail. While the single slope barrier design was originally intended for use as a median barrier, there is no reason why it could not be used as a bridge rail. The key difference between the median barrier and the bridge rail applications would be the height of the barrier, which is 1.07 m (42 in) for the median barrier and 0.81 m (32 in) for the bridge rail. Based on results of previous crash tests, the impact performance of the barrier should not be adversely affected when the barrier height is lowered from 1.07 to 0.81 m (42 to 32 in). The other difference is that the bridge rail is tied into the bridge deck while the median barrier is keyed in place with an asphalt overlay. However, since the barrier remains essentially rigid in both applications, there should not be any effect on its impact performance.

This chapter presents the results of full-scale crash tests conducted on this single slope concrete bridge rail and the evaluation of its impact performance. Testing and evaluation was performed in accordance with guidelines outlined in NCHRP Report 350 and the 1989 American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings.*

9.1 TEST INSTALLATION

A cross-section of the test installation is shown in figure 40. Precast single slope median barrier sections, previously fabricated by TTI in another study, were used for the test installation. The use of the precast single slope median barrier sections saved the expense of building a simulated bridge deck and the bridge rail. The rationale for this approach was that, as long as the barrier remained rigid, it really would not matter if the bridge rail was tied into a simulated bridge deck or not. The concern was more with the shape and geometrics of the single slope bridge rail and not the strength of the rail or its tie-in to the bridge deck.

Four 9.14-m (30-ft) precast barrier sections were used for a total installation length of 36.6 m (120 ft). The barrier sections were connected with channel connectors at the bottom and rebar grids were placed in the grid slots and grouted in place. A 254-mm- (10-in-) deep ditch was dug for placement of the barrier sections so that the height of the barrier above ground level was reduced from 1.07 to 0.81 m (42 to 32 in). The bottom of the ditch was lined with base materials to ensure that the foundation for the barrier was level and smooth. To ensure that the barrier sections would remain rigid during the impacts, the barrier section within which the impacts would occur was doweled into the existing concrete pavement with no. 5 rebars spaced at 0.91 m (3 ft) center to center. Also, after the barrier was installed in the ditch, the back of the barrier was keyed with a concrete overlay, 0.61 m (24 in) wide and 102 mm (4 in) thick, and the area between the existing concrete pavement and the front of the barrier was backfilled with grout to make sure that the barrier would remain rigid upon impact.

WaDOT plans to use a bridge rail height of 864 mm (34 in), which allows for a future overlay of 51 mm (2 in). However, the crash tests were conducted with a bridge rail height of 813 mm (32 in) since the lower rail height was considered a more critical test condition.

9.2 CRASH TEST CONDITIONS

In accordance with requirements set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings* for a Performance Level 2 (PL-2) bridge rail, the following three crash tests are required:

1. An 817-kg (1800-lb) passenger car impacting the bridge rail at a nominal speed and angle of 96.6 km/h (60 mi/h) and 20 degrees,

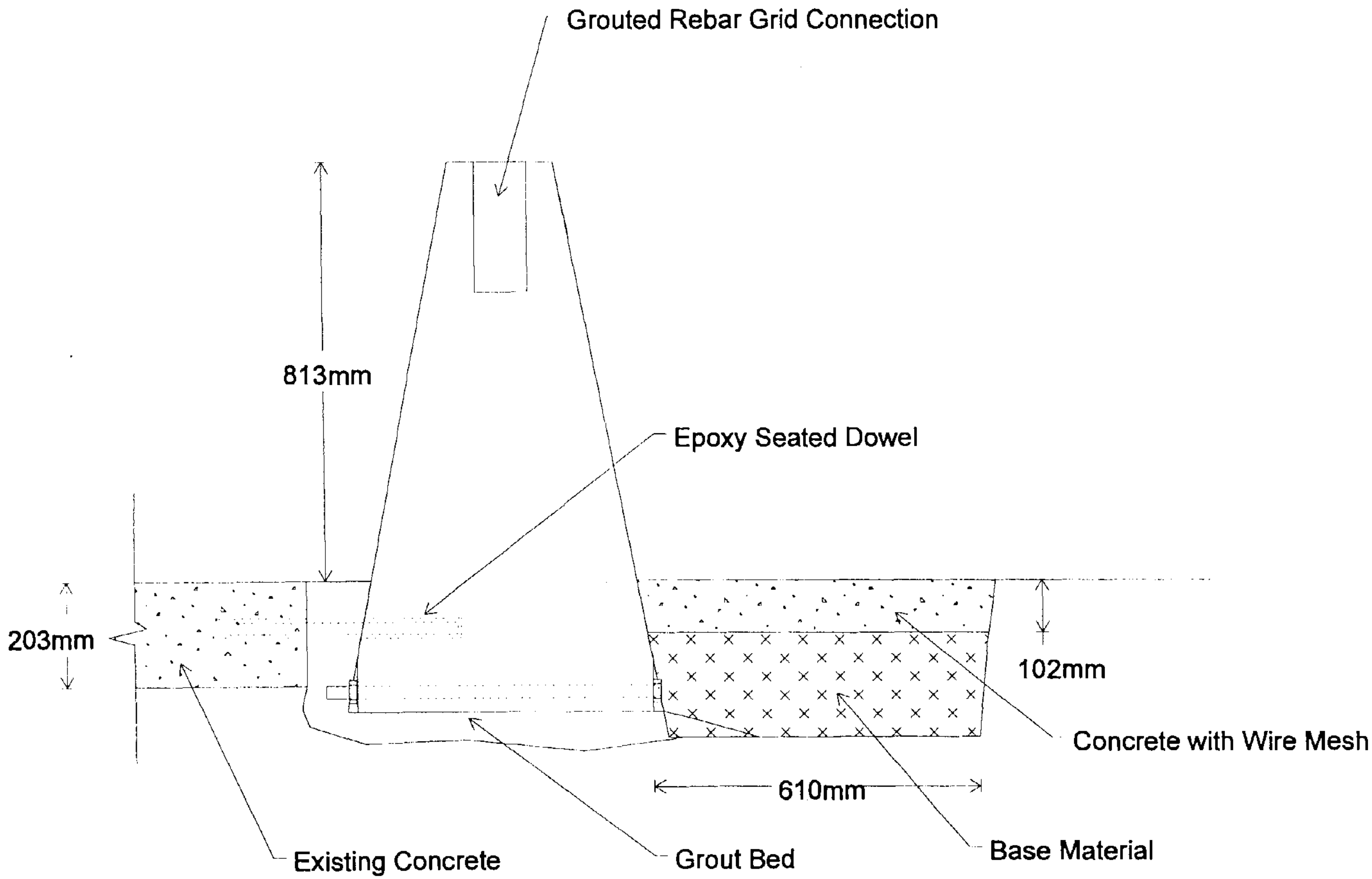


Figure 40. Cross-section of the single slope bridge rail test installation.

2. A 2452-kg (5400-lb) pickup truck impacting the bridge rail at a nominal speed and angle of 96.6 km/h (60 mi/h) and 20 degrees, and
3. An 8172-kg (18 000-lb) single-unit truck impacting the bridge rail at 80.5 km/h (50 mi/h) and 15 degrees.

The above crash test matrix was modified upon mutual agreement between FHWA and WaDOT. The 817-kg (1800-lb) passenger car severity test was considered unnecessary and deleted from the crash test matrix. As mentioned previously, the single slope concrete median barrier successfully passed the large car structural adequacy test and the small car severity test in accordance with guidelines set forth in NCHRP Report 230. Based on the results of those crash tests, it was believed that the barrier height would have little or no effect on the small car severity test and there was, therefore, no need to repeat the test.

As for the 2452-kg (5400-lb) pickup truck structural adequacy test at 96.6 km/h (60 mi/h) and 20 degrees, it should also perform similarly to the 2043-kg (4500-lb) passenger car test at 96.6 km/h (60 mi/h) and 25 degrees. However, while the large car successfully met the guidelines set forth in NCHRP Report 230, the vehicle exhibited a tendency to climb up on the barrier. There was, therefore, concern that vehicle stability might become a problem with the pickup truck when the barrier height was reduced from 1.07 to 0.81 m (42 to 32 in). Thus, the crash test with the pickup truck was included. It was also decided that the test conditions for the pickup truck test would be in accordance with test level 4 (TL-4) of NCHRP Report 350 requirements (i.e., a 2000-kg (4405-lb) pickup truck impacting the bridge rail at a nominal speed and angle of 100 km/h (62.2 mi/h) and 25 degrees).

In summary, the actual crash test matrix used to evaluate the impact performance of this single slope concrete bridge rail design included the following two crash tests:

1. A 2000-kg (4405-lb) pickup truck impacting the bridge rail at a nominal speed and angle of 100 km/h (62.2 mi/h) and 25 degrees.
2. An 18 000-lb (8172-kg) single-unit truck impacting the bridge rail at a nominal speed and angle of 80.5 km/h (50 mi/h) and 15 degrees.

9.3 TEST NUMBER 471470-15 (AASHTO PL-2 PICKUP TRUCK TEST)

Test vehicle: 1985 Chevrolet C-20 Pickup	Impact speed: 97.2 km/h (60.4 mi/h)
Test inertia weight: 2000 kg (4405 lb)	Impact angle: 25.5 degrees
Gross static weight: 2076 kg (4573 lb)	

The vehicle impacted the bridge rail 12.2 m (40.0 ft) from the upstream end. The right front tire of the vehicle began to climb the face of the barrier upon impact. Shortly afterwards, the left front tire became airborne as the vehicle began to redirect. The rear of the vehicle contacted the barrier and the rear wheels became airborne. The vehicle became parallel to the barrier traveling at 84.4 km/h (52.5 mi/h). The vehicle exited the barrier airborne traveling at a speed of 76.6 km/h (47.6 mi/h) and an angle of 3.3 degrees. The right front tire came back into contact with the pavement and the tire and rim separated from the wheel hub subsequent to the impact with the pavement. The right rear tire contacted the pavement and as the vehicle continued moving away from the barrier, the right rear tire and rim became detached from the wheel hub. The vehicle came to rest 77.4 m (254 ft) downstream and 21.2 m (69.5 ft) to the traffic side of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 41.

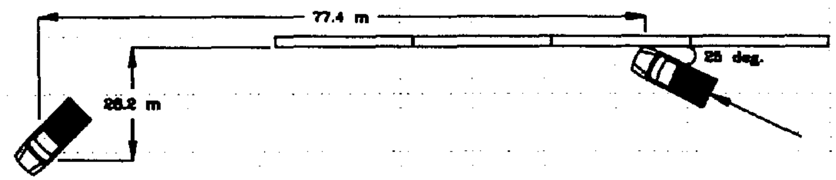
The barrier received only cosmetic damage (i.e., scrapes and tire marks) and two small cracks on the barrier. Maximum permanent movement of the barrier was 6 mm (0.3 in) at the impact area. The vehicle was in contact with the barrier for 4.2 m (13.9 ft). The vehicle sustained moderate to extensive damage. Maximum deformation into the occupant compartment was 140 mm (5.5 in) at the firewall area, and maximum exterior crush at the right front corner at bumper height of the vehicle was 409 mm (16.1 in). The right front wheel was pushed rearward 119 mm (4.7 in) and the frame was bent. In addition, the front bumper, grill, hood, radiator, and the right front control arm were damaged and the entire right-side body panels were dented and scraped.

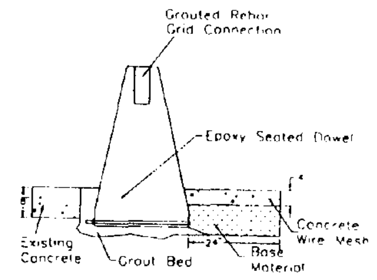
9.4 TEST NUMBER 471470-16 (AASHTO PL-2 SINGLE-UNIT TRUCK TEST)

Test vehicle:	1982 GMC single-unit truck	Impact speed: 82.1 km/h (51.0 mi/h)
Empty weight:	5262 kg (11,590 lb)	Impact angle: 10.0 degrees
Gross static weight:	8172 kg (18,000 lb)	

The vehicle impacted the bridge rail 13.7 m (45.0 ft) from the upstream end. Shortly after impact with the bridge rail, the front axle separated from the vehicle. The vehicle began to redirect significantly and the right front edge of the bumper reached the top of the bridge rail. The right lower corner and edge of the box van set down on top of the rail and rode along in this fashion until the vehicle rode off the end of the bridge rail test installation. The box van reached a maximum roll angle of 23 degrees and the cab reached a maximum roll angle of 25 degrees. The box van began to right itself. The vehicle subsequently came to rest upright 65.4 m (214.5 ft) downstream and 2.6 m (8.5 ft) to the left of the point of impact (i.e., to the traffic side of the bridge rail). A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 42.

The barrier received only cosmetic damage (i.e., gouges, scrapes, and tire marks). Maximum permanent movement of the barrier was 2 mm (0.1 in) at the impact area. The vehicle was in contact with the barrier for 15.6 m (51.2 ft). The vehicle sustained extensive damage to the front suspension. Maximum crush at the right front corner of the vehicle was 178 mm (7.0 in). The front axle was separated from the vehicle and the spring shackles, U-bolts, shocks, mounts, tie rods, and steering arm were damaged. In addition, damage was sustained by the front bumper, the right front quarter panel, and the right and left running boards. The windshield was cracked and the fuel tank was scraped.



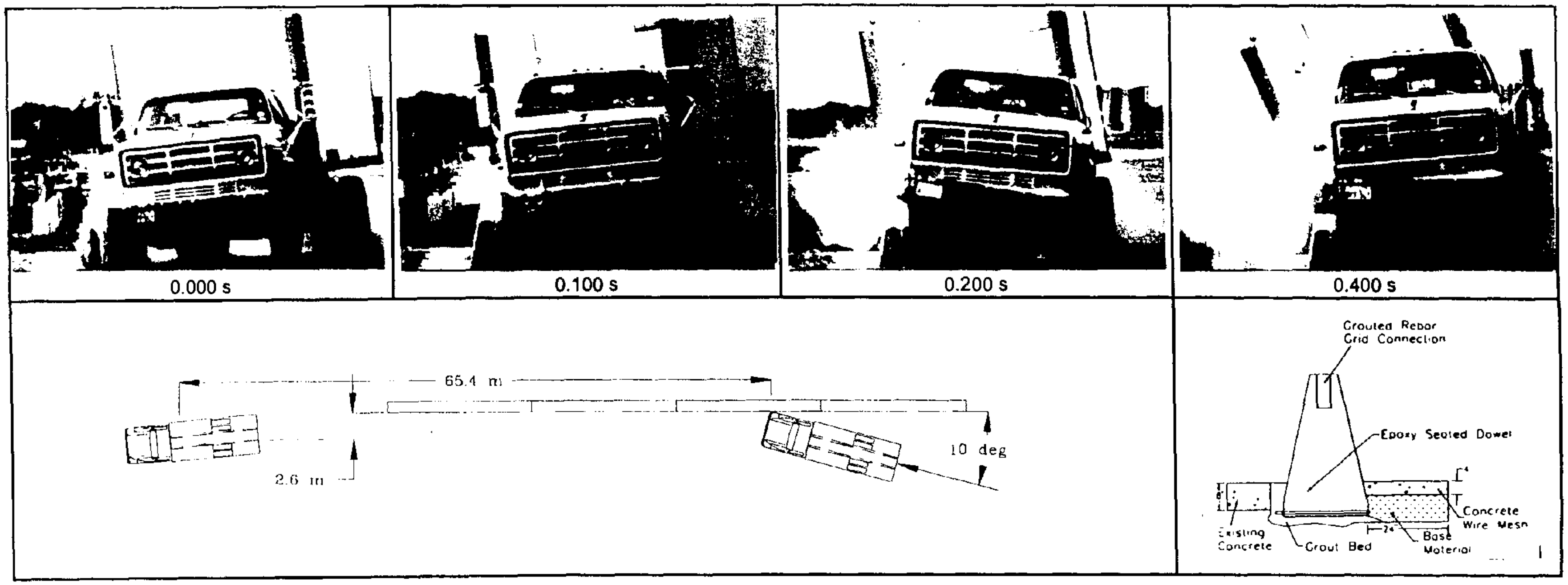


General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-15
Date	05/03/93
Test Article	
Type	Bridge Rail
	Single Slope Concrete
Installation Length (m)	36.6 (120 ft)
Size and/or dimension and material of key elements	813-mm- (32-in-) High concrete
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	2000 P
Model	1985 Chevrolet Custom
Mass (kg) Curb	1993 (4390 lb)
Test Inertial	2000 (4405 lb)
Dummy	76 (167 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	97.2 (60.4 mi/h)
Angle (deg)	25.5
Exit Conditions	
Speed (km/h)	76.6 (47.6 mi/h)
Angle (deg)	3.3
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.4 (17.7 ft/s)
y-direction	7.8 (25.6 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-6.1
y-direction	-12.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-7.3
y-direction	-13.3
z-direction	-5.6

Test Article Deflections (mm)	
Dynamic	N/A
Permanent	6 (0.3 in)
Vehicle Damage	
Exterior	
VDS	01RD5
CDC	01FREK2 & 01RDEW2
Interior	
OCDI	RF0020000
Maximum Exterior Vehicle Crush (mm)	409 (16.1 in)
Max. Occ. Compart. Deformation (mm)	140 (5.5 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	30
Max. Pitch Angle (deg)	7
Max. Yaw Angle (deg)	40

Figure 41. Summary of results for test 471470-15.



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-16
Date	05/06/93
Test Article	
Type	Bridge Rail
	Single Slope Concrete
Installation Length (m)	36.6 (120 ft)
Size and/or Dimension and Material of Key Elements	813-mm- (32-in-) High concrete
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	8000 S
Model	1982 GMC Single-Unit Truck
Mass (kg) Curb	5262 (11 590 lb)
Test Inertial	8172 (18 000 lb)
Dummy	N/A
Gross Static	8172 (18 000 lb)

Impact Conditions	
Speed (km/h)	82.1 (51.0 mi/h)
Angle (deg)	10.0
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.3 (7.5 ft/s)
y-direction	3.5 (11.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.3
y-direction	-2.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-1.3
y-direction	-2.7
z-direction	2.4

Test Article Deflections (mm)	
Dynamic	N/A
Permanent	2 (0.1 in)
Vehicle Damage	
Exterior	
VDS	N/A
CDC	N/A
Interior	
OCDI	RF0000000
Maximum Exterior Vehicle Crush (mm)	178 (7.0 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	19.8
Max. Pitch Angle (deg)	-2.3
Max. Yaw Angle (deg)	-8.2

Figure 42. Summary of results for test 471470-16.

9.5 TEST NUMBER 471470-17 (AASHTO PL-2 SINGLE-UNIT TRUCK TEST)

Test vehicle: 1985 GMC single-unit truck Empty weight: 5207 kg (11,470 lb) Gross static weight: 8172 kg (18,000 lb)	Impact speed: 82.5 km/h (51.3 mi/h) Impact angle: 17.9 degrees

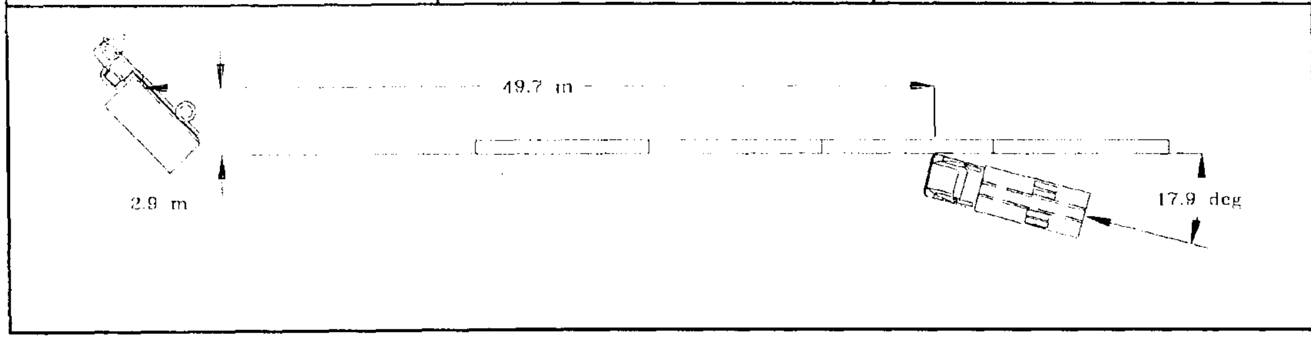
In the single unit truck test previously described under test no. 471470-16, the impact angle was 10 degrees instead of the required 15 degrees. It was therefore decided to repeat the single-unit truck test. The vehicle impacted the bridge rail 13.1 m (43.0 ft) from the upstream end. Upon impact, the right front tire began to climb the face of the bridge rail and, shortly afterwards, the front axle became partially separated from the vehicle. The vehicle began to redirect significantly and the right front edge of the bumper reached the top of the bridge rail. The box van began to roll to the right and the lower right corner and edge of the box van set down on top of the rail and rode along in this fashion until the vehicle rode off the end of the bridge rail test installation. The cab and box van reached a maximum roll angle of 53 degrees. After the vehicle rode off the end of the bridge rail test installation, the front axle separated from the vehicle as the front end contacted the pavement and the rear tires of the vehicle dug into the dirt. The vehicle began to roll to the left and eventually rolled onto its left side. The vehicle came to rest 49.7 m (163.0 ft) downstream and 2.9 m (9.5 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 43.

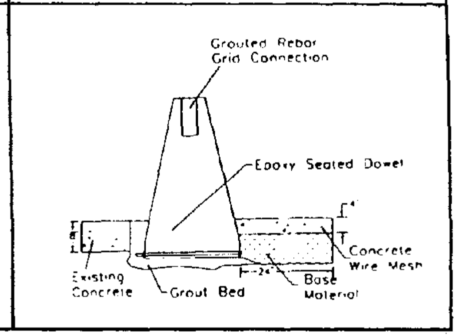
The barrier received only cosmetic damage (i.e., gouges, scrapes and tire marks). Maximum permanent movement of the barrier was 2 mm (0.1 in) at the impact area. The vehicle was in contact with the barrier for 23.5 m (77.0 ft). Maximum crush at the right front corner of the vehicle was 229 mm (9.0 in). The front axle was separated from the vehicle and the spring shackles, U-bolts, mounts, tie rods, and steering arm were damaged. In addition, damage was sustained by the front bumper and grill, the right front fender, door, and running board. The entire left side of the vehicle sustained dents and scrapes due to rollover on the left side. The fuel tanks were scraped on both sides.

9.6 SUMMARY OF FINDINGS

Results of the three full-scale crash tests (test nos. 471470-15 through 471470-17) to evaluate the impact performance of the single slope concrete bridge rail are summarized in Tables 19 through 21, respectively. The single slope concrete bridge rail was judged to have successfully met all evaluation criteria set forth in NCHRP Report 350 and the 1989 AASHTO *Guide Specifications for Bridge Railings.*

For the pickup truck test (test no. 471470-15), the single slope concrete bridge rail contained and smoothly redirected the vehicle. There were no detached elements or debris to cause undue hazard to occupants of the vehicle or to adjacent traffic. The vehicle sustained moderate damage with minor deformation into the occupant compartment. The vehicle remained upright and relatively stable during the collision period; however, there was some





General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-17
Date	05/06/93
Test Article	
Type	Bridge Rail
	Single Slope Concrete
Installation Length (m)	36.6 (120 ft)
Size and/or Dimension and Material of Key Elements	813-mm- (32-in-) High concrete
Soil Type and Condition	N/A
Test Vehicle	
Type	Production Model
Designation	8000 S
Model	1985 GMC Single-Unit Truck
Mass (kg) Curb	5207 (11 470 lb)
Test Inertial	8172 (18 000 lb)
Dummy	N/A
Gross Static	8172 (18 000 lb)

Impact Conditions	
Speed (km/h)	82.5 (51.3 mi/h)
Angle (deg)	17.9
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.9 (9.7 ft/s)
y-direction	2.8 (9.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-2.7
y-direction	-10.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-2.0
y-direction	-5.6
z-direction	-1.4

Test Article Deflections (mm)	
Dynamic	N/A
Permanent	2 (0.1 in)
Vehicle Damage	
Exterior	
VDS	N/A
CDC	N/A
Interior	
OCDI	RF0000000
Maximum Exterior Vehicle Crush (mm)	229 (9.0 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	53.0
Max. Pitch Angle (deg)	4.3
Max. Yaw Angle (deg)	-18.9

Figure 43. Summary of results for test 471470-17.

Table 19. Assessment of results of test 471470-15 (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute | Test No.: 471470-15 | Test Date: 05/03/93

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The single slope concrete bridge rail contained and redirected the vehicle; the vehicle did not penetrate, underride, or override the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris. There was some minor deformation into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Vehicle remained upright and stable during the collision; however, there was moderate pitching and yawing after exiting the bridge rail.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Vehicle exited the bridge rail at 3.3 deg. Final point of rest was 77 m down and 21 m toward the traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal occupant impact velocity was 5.4 m/s (17.7 ft/s) and the longitudinal ridedown acceleration was 6.1 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle exited the bridge rail at 3.3 degrees at loss of contact.	Pass

Table 20. Assessment of results of test 471470-16 (according to 1989 AASHTO Guide).

	AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a.	The test 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.	The single slope concrete bridge rail contained the vehicle. Neither the vehicle nor cargo penetrated or went over the installation.	Pass
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.	There were no detached elements or debris to present undue hazard to occupants of the vehicle or other traffic.	Pass
c.	Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no deformation or intrusion into the occupant compartment.	Pass
d.	The vehicle shall remain upright during and after collision.	Vehicle remained upright during and after collision.	Pass
e.	The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f.	The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment Not attainable	Not attainable
g.	The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal: 9.2 (30); Lateral: 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal: 15; Lateral: 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal: 2.3 (7.5); Lateral: 3.5 (11.5) Occupant Ridedown Accelerations - g's Longitudinal: -1.3; Lateral: -2.6	N/A
h.	Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (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 6 m (20 ft) from the line of the traffic face of the railing.	Vehicle rode off the end of the bridge rail and subsequently came to rest 65 m (215 ft) down from the point of impact and 2.6 m (8.5 ft) toward traffic.	Pass

*For Single-Unit Truck: A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.

Table 21. Assessment of results of test 471470-17 (according to 1989 AASHTO Guide).

	AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a.	The test 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.	The single slope concrete bridge rail contained the vehicle. Neither the vehicle nor cargo penetrated or went over the installation.	Pass
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.	There were no detached elements or debris to present undue hazard to occupants of the vehicle or other traffic.	Pass
c.	Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no deformation or intrusion into the occupant compartment.	Pass
d.	The vehicle shall remain upright during and after collision.	Vehicle remained upright during and after collision.	Pass
e.	The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f.	The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment Not attainable	Not attainable
g.	The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 2.9 (9.7); Lateral 2.8 (9.3) Occupant Ridedown Accelerations - g's Longitudinal -2.7; Lateral -10.2	N/A
h.	Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (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 6 m (20 ft) from the line of the traffic face of the railing.	Vehicle rode off the end of the bridge rail and subsequently came to rest 50 m (163 ft) down from the point of impact and 0.9 m (9.5 ft) behind the bridge rail.	Pass

*For Single-Unit Truck: A, B, and C are required. D, E, F, and H are desired. G is not applicable for this test.

moderate pitching and yawing after the vehicle exited from the bridge rail. While the vehicle came to rest 21.2 m (67.5 ft) from the traffic side of the bridge rail, the trajectory of the vehicle was judged to pose minimal potential hazard to adjacent traffic. Part of the vehicle trajectory could be attributed to the separation of the tires and rims from the wheel hubs for the two right-side tires. Also, the exit angle of 3.3 degrees was substantially less than 60 percent of the impact angle. The occupant impact velocities and ridedown accelerations were well within the limits set forth in NCHRP Report 350 and the 1989 AASHTO *Guide Specifications for Bridge Railings*.

For the two single-unit truck tests (test nos. 471470-16 and 471470-17), the single slope concrete bridge rail contained and redirected the test vehicles and did not allow the vehicles to penetrate or go over the bridge rail. There were no detached elements or debris from the bridge rail to present undue hazard to occupants in the vehicles or other adjacent traffic. Integrity of the occupant compartment was maintained. In test no. 471470-16, the vehicles remained upright and relatively stable during and after the collision. In test no. 471470-17, the vehicle remained upright during collision with the bridge rail, but then rolled over onto its left side (non-impact side) after exiting from the bridge rail test installation. The rollover occurred on the traffic side of the bridge rail, which is considered acceptable under the evaluation criteria set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings*. The vehicle trajectory did not pose any potential hazard to adjacent traffic in both tests.

Note that the impact angles for two single-unit truck tests was too low (10 degrees) in one test and too high (17.9 degrees) in the second test. Since both tests successfully met all evaluation criteria, it is reasonable to argue that the single slope concrete bridge rail would have performed satisfactorily had the impact angle been at the required 15 degrees. A cursory review of the two tests showed that, for the test with the higher impact angle, the vehicle was less stable with a much higher roll angle toward the barrier and a slightly higher climb on the barrier during impact with the bridge rail. Also, the vehicle rolled over after exiting from the bridge rail in the test with the higher impact angle.

X. NETC PL-2 BRIDGE RAIL DESIGN

A new metal post-and-beam bridge rail with concrete curb was designed by the New England Transportation Consortium (NETC). This bridge railing system was designed to meet Performance Level 2 (PL-2) requirements set forth in the 1989 AASHTO *Guide Specifications For Bridge Railings*, which include the following three crash tests:

1. An 817-kg (1800-lb) passenger car impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
2. A 2452-kg (5400-lb) pickup truck impacting the bridge railing at a nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees.
3. An 8172-kg (18 000-lb) pickup truck impacting the bridge railing at a nominal impact speed and angle of 80.5 km/h (50 mi/h) and 15 degrees.

The 817-kg (1800-lb) passenger car and the 2452-kg (5400-lb) pickup truck tests were conducted with successful results (test nos. 471470-18 and 471470-19). However, the bridge deck sustained structural damage in the pickup truck test. This resulted in some revisions to the design of the bridge deck to accommodate the higher loading anticipated with the single-unit truck crash test.

At the same time, the FHWA adopted the NCHRP Report 350 as the official guidelines for crash testing and evaluation of roadside safety features. The single-unit truck test under NCHRP Report 350 for test level 4 (TL-4) is similar to that under the Guide Specifications except for the weight of 8000 kg (17 636 lb) and impact speed of 80 km/h (49.7 mi/h). It was therefore decided to follow the guidelines under NCHRP Report 350 for the TL-4 single-unit truck test (test no. 471470-29), which was conducted with successful results.

Results of these three crash tests are presented in this chapter.

10.1 TEST INSTALLATION

A schematic of the test installation is shown in figure 44, and photographs of the completed installation are shown in figure 45. The major components of the test installation are as follows:

1. A 30.5-m- (100-ft-) long, 203-mm- (8-in-) thick simulated bridge deck;
2. A 533-mm- (21-in-) wide, 229-mm- (9-in-) thick curb section;
3. 13 W6×25 rail posts mounted 2.4 m (8.0 ft) on center; and
4. Two tubular steel rails. The top rail is a TS 203 mm × 102 mm × 7.9 mm (8 in × 4 in × 5/16 in) and the bottom rail is a TS 102 mm × 102 mm × 6.4 mm (4 in × 4 in × 1/4 in).

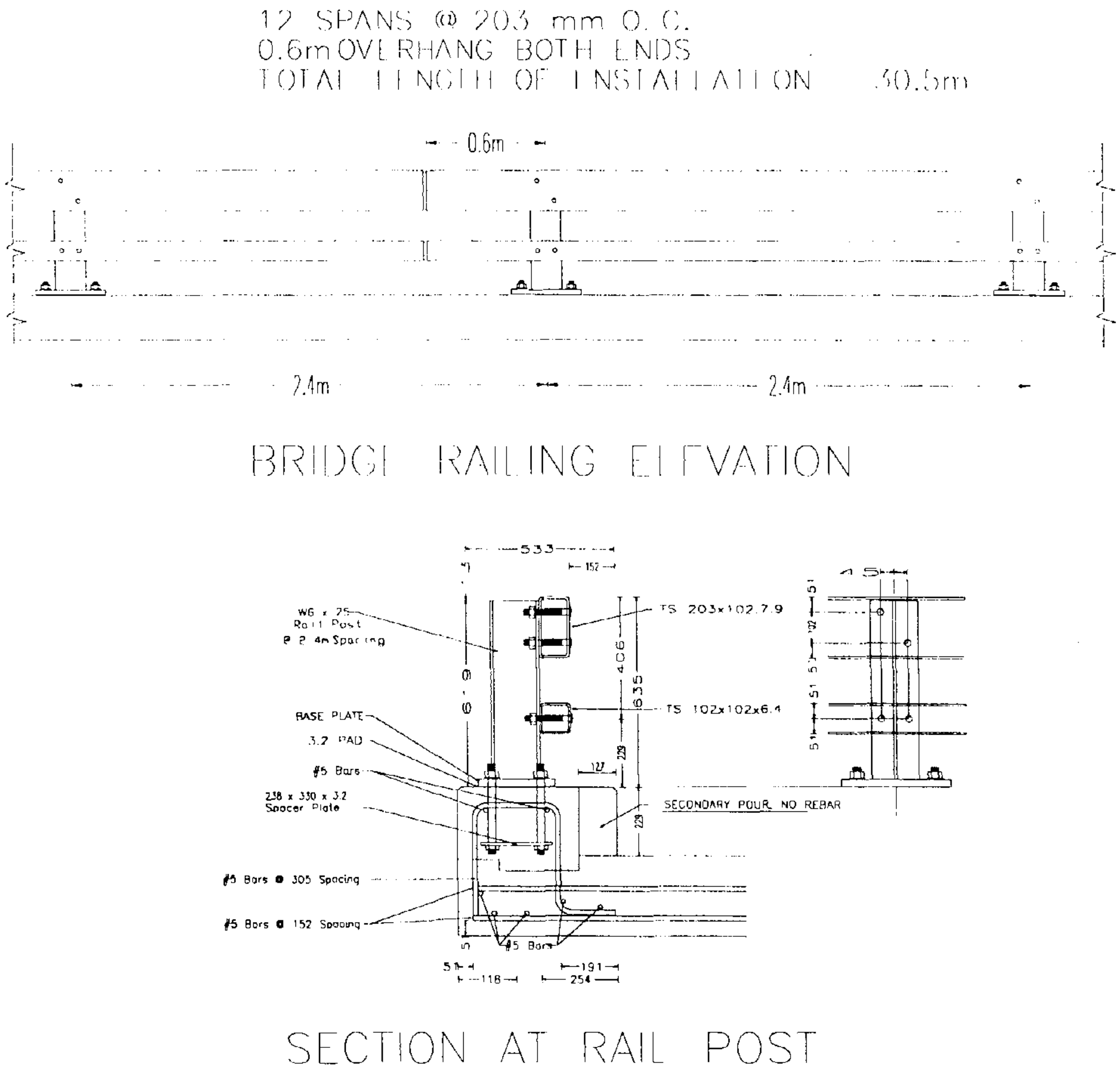
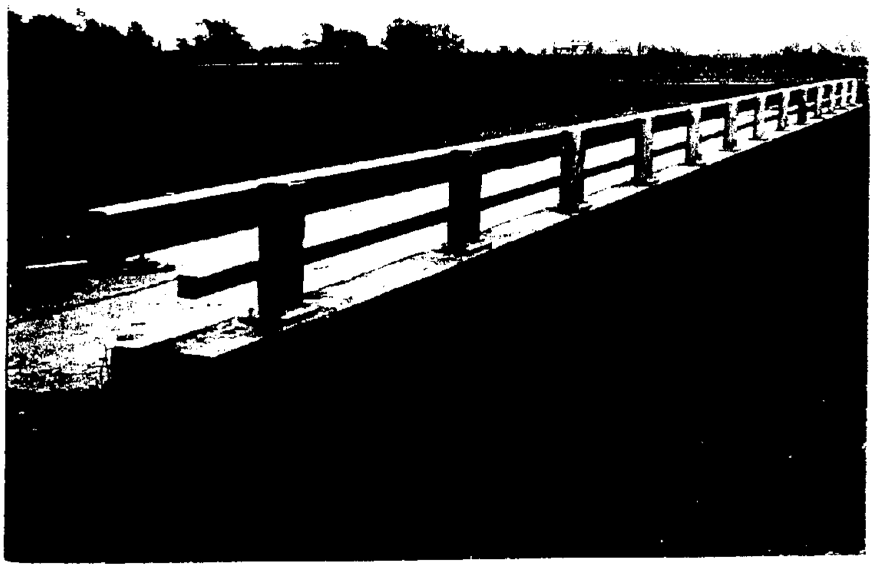


Figure 44. Details of NETC bridge railing used in tests 471470-18 and 471470-19.



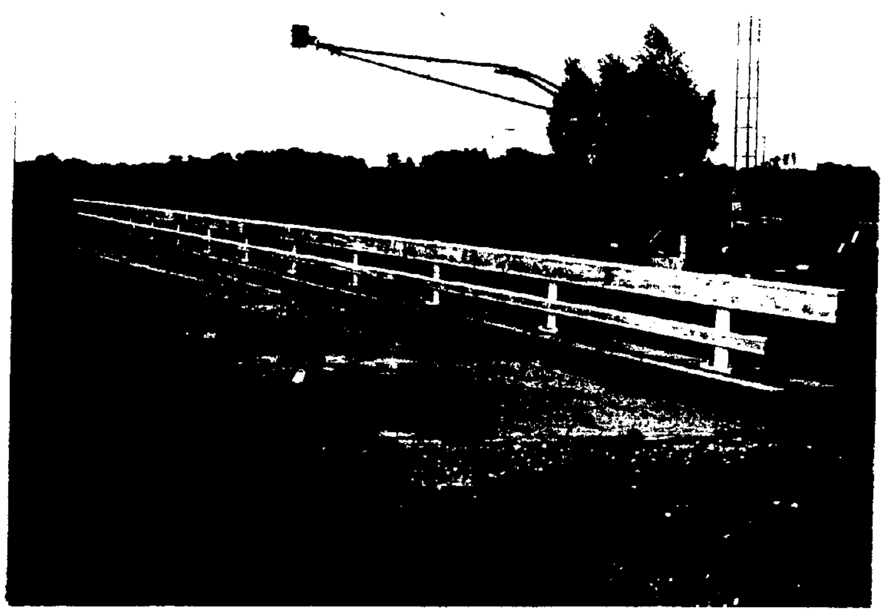


Figure 45. Photographs of test installation for 471470-18 and 471470-19.

The simulated bridge deck consisted of a 203-mm- (8-in-) thick cantilevered concrete section with #5 bars on 152-mm- (6-in-) centers top and bottom. Stirrups, made of #5 bars, were on 305-mm (12-in) centers in the curb section. The curb section was 229-mm (9-in) thick with a 51-mm (2-in) shear key and 533-mm (21-in) wide, including a 127-mm (5-in-) thick facing cast in a separate pour on the front of the curb to simulate a granite facing planned for use with the bridge railing. The face of the curb section protruded 152 mm (6 in) from the face of the tubular steel rails. Four 229-mm- (9-in-) long, 25-mm- (1-in-) diameter, double-threaded studs were placed in a 237-mm × 330-mm × 3.2-mm (9-3/8-in × 13-in × 1/8-in) spacer plate for anchoring of the rail posts.

The bridge railing consisted of two tubular steel sections. A TS 203-mm × 102-mm × 7.9-mm (8-in × 4-in × 5/16-in) rail element was attached to the top of the posts with two 152-mm- (6-in-) long, 19.1-mm- (3/4-in-) diameter round headed bolts. The TS 102-mm × 102-mm × 6.4-mm (4-in × 4-in × 1/4-in) bottom rail was attached to the posts with similar bolts. The rail posts were fabricated from W6×25 steel post sections shop welded to a 254-mm × 356-mm × 25.4-mm (10-in × 14-in × 1-in) steel base plate. The overall height of the rail post was 618 mm (24-3/8 in). The top of the top rail was 635 mm (25 in) above the top of the curb section for a total height of 864 mm (34 in) above the pavement surface.

The bridge rail was successfully crash tested with a 817-kg (1800-lb) passenger car and a 2452-kg (5400-lb) pickup truck (test nos. 471470-18 and 471470-19). However, the bridge deck sustained structural damage in the pickup truck test. This resulted in some revisions to the design of the bridge deck to accommodate the higher loading anticipated with the single-unit truck crash test. The revisions included: increasing the thickness of the bridge deck; widening the width of the curb and deck to increase the cover on the anchor bolts; additional stirrups and distribution bar at the post anchors; and increasing the thickness of the spacer plate and the length of the anchor bolts. A schematic of the redesigned NETC bridge rail and deck test installation is shown in figure 46, and photographs of the completed installation are shown in figure 47.

10.2 TEST NUMBER 471470-18 (AASHTO PL-2 SMALL CAR TEST)

Test vehicle: 1986 Yugo GV	Impact speed: 100.9 km/h (62.7 mi/h)
Test inertia weight: 817 kg (1800 lb)	Impact angle: 20.6 degrees
Gross static weight: 894 kg (1970 lb)	

The vehicle impacted the bridge railing mid-span between posts 3 and 4 (post 1 was the first post at the upstream end of the bridge railing) or 1.02 m (40 in) downstream from post 3. The vehicle became parallel to the bridge railing traveling at 92.0 km/h (57.2 mi/h). The vehicle lost contact with the bridge railing traveling at a speed of 88.7 km/h (55.1 mi/h) and at an exit angle of 2.2 degrees. The brakes on the vehicle were applied and the vehicle subsequently came to rest 64.6 m (212 ft) down from and 0.9 m (3 ft) in front of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 48.

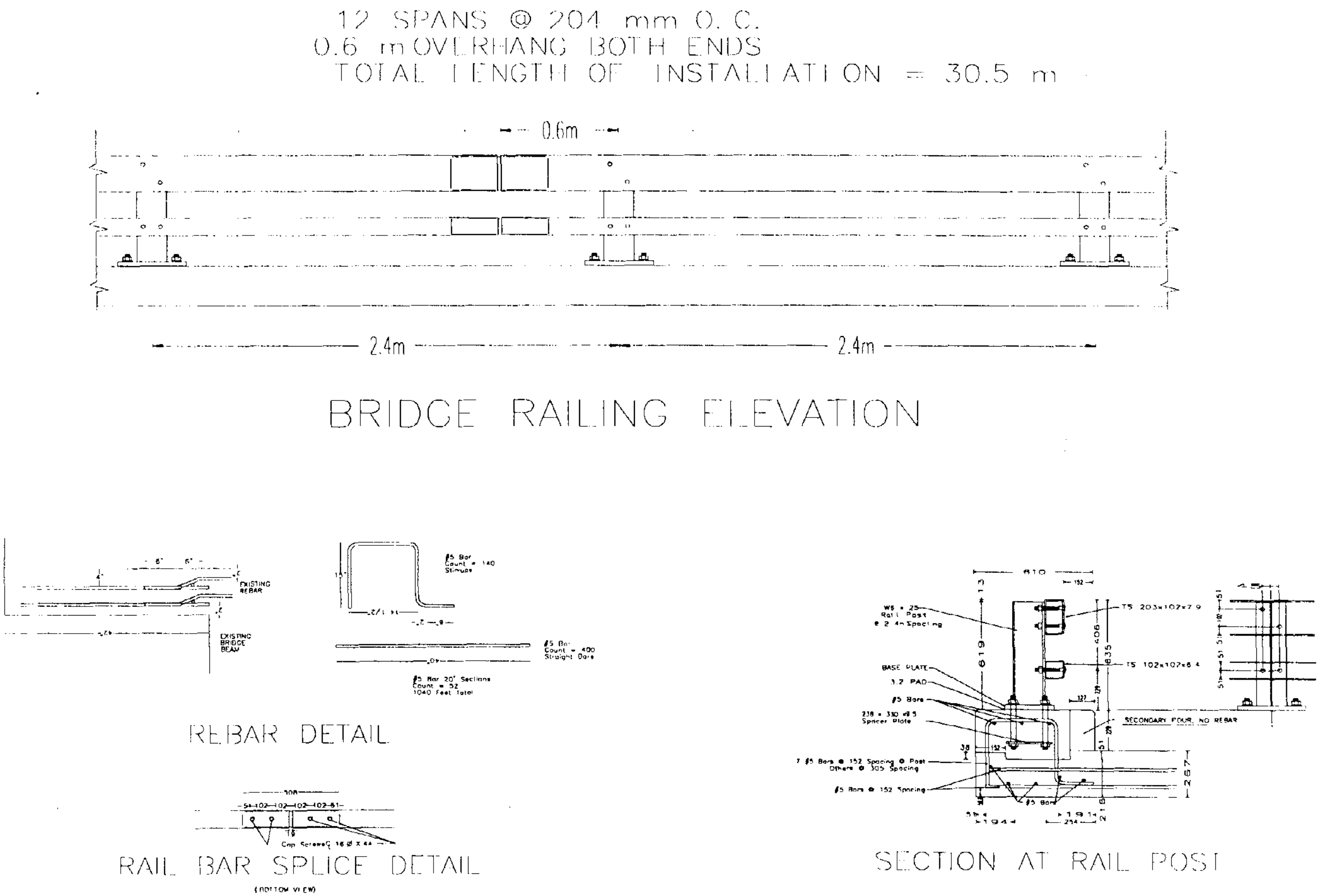


Figure 46. Details of NETC bridge railing used in test 471470-29.

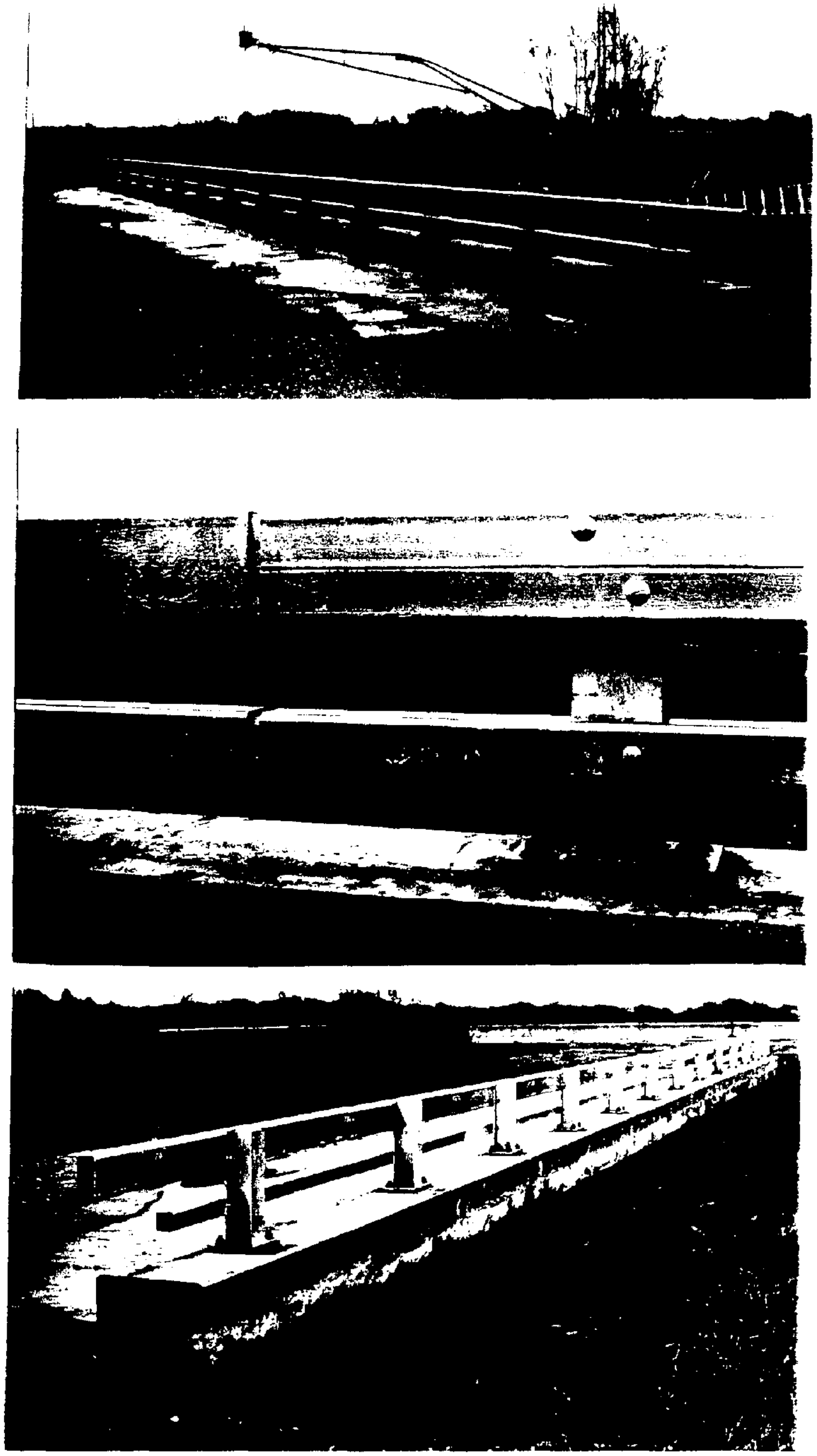
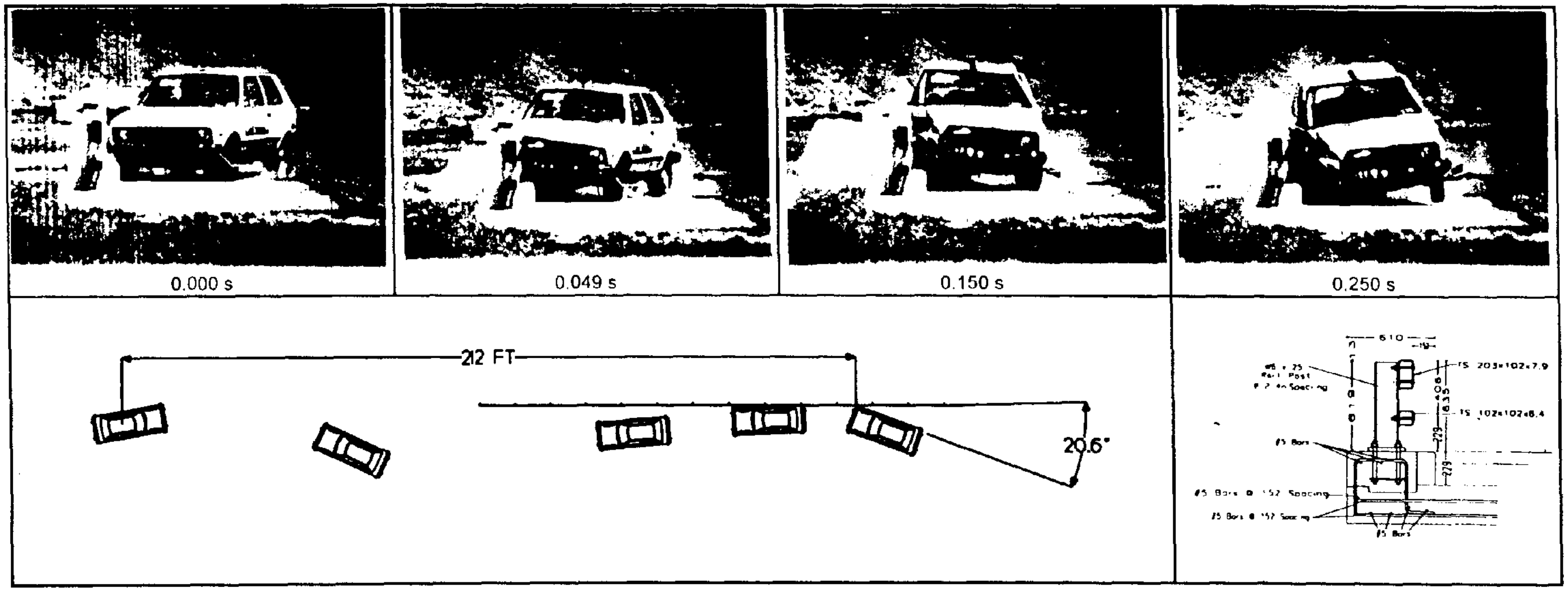


Figure 47. NETC bridge railing before test 471470-29.



General Information

Test Agency	Texas Transportation Institute
Test No.	7147-18
Date	07/20/93

Test Article

Type	Bridge Rail
	NETC Bridge Rail
Installation Length (m)	30.5 (100 ft)
Size and/or Dimension and Material of Key Elements	Tubular Steel Rail Elements on W6 X 25 Steel Posts @ 2.4 m on 241-mm Curb
Soil Type and Condition	Concrete Bridge Deck, Dry

Test Vehicle

Type	Production Model
Designation	820 C
Model	1986 Yugo GV
Mass (kg) Curb	809 (1782 lb)
Test Inertial	817 (1800 lb)
Dummy	77 (170 lb)
Gross Static	894 (1970 lb)

Impact Conditions

Speed (km/h)	100.9(62.7 mi/h)
Angle (deg)	20.6

Exit Conditions

Speed (km/h)	88.7 (55.1 mi/h)
Angle (deg)	2.2

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	5.2 (16.9 ft/s)
y-direction	8.4 (27.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-1.6
y-direction	-6.8
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-6.1
y-direction	-15.2
z-direction	-2.6

Test Article Deflections (mm)

Dynamic	Not Available
Permanent	6 (0.25 in)

Vehicle Damage

Exterior	
VDS	01RFQ-3
CDC	01FREK2
	03RDES1
Interior	
OCDI	RS0100000
Maximum Exterior Vehicle Crush (mm)	124 (4.9 in)
Max. Occ. Compart. Deformation (mm)	32 (1.3 in)

Post-Impact Behavior

Max. Roll Angle (deg)	15
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	-32

Figure 48. Summary of results for test 471470-18.

The bridge railing and curb received only minor cosmetic damage. The vehicle was in contact with the bridge railing for a total length of 4.0 m (13.2 ft). The vehicle sustained damage to the right side. Maximum crush at the right front corner at bumper height was 124 mm (4.9 in), with 20 mm (0.8 in) of crush at the right "A" pillar. The wheelbase on the right side was shortened by 108 mm (4.3 in). The right front strut and sway bar were damaged. Also, damage was done to the front bumper, hood, grill, right front fender, right front rim, right door, right rear quarter panel, and right rear rim.

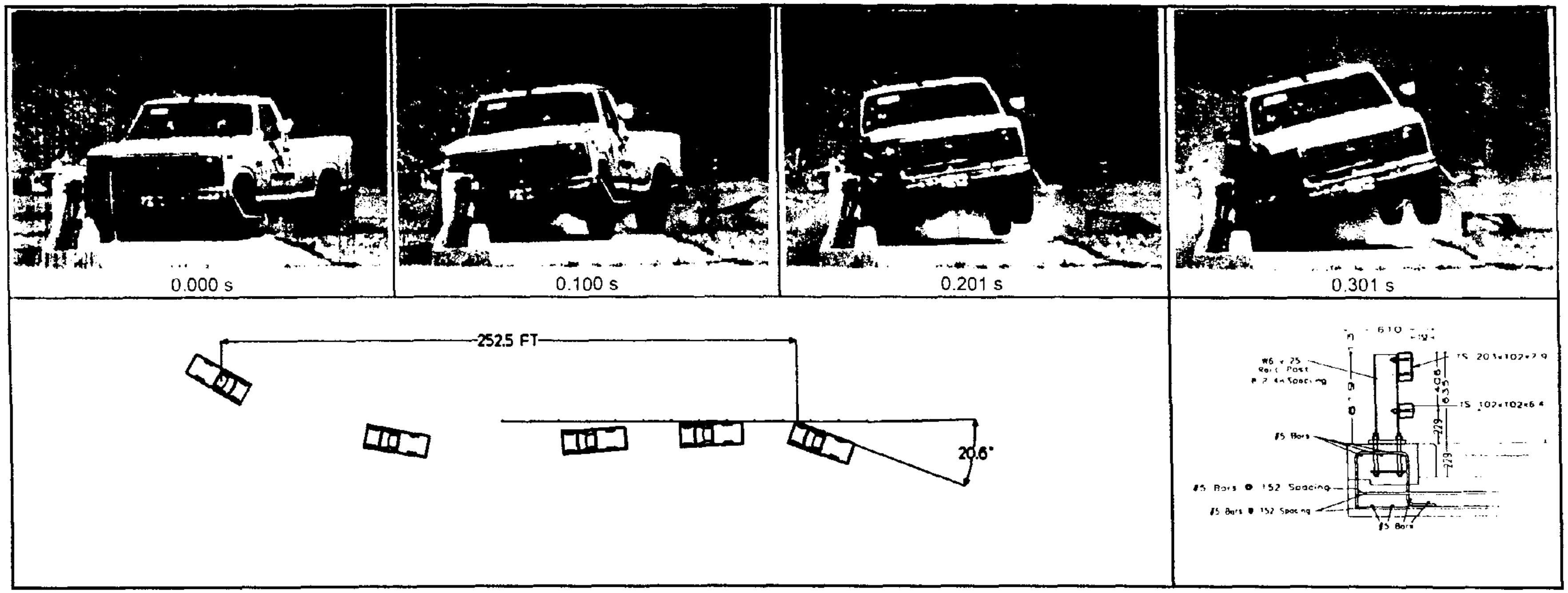
10.3 TEST NUMBER 471470-19 (AASHTO PL-2 PICKUP TRUCK TEST)

Test vehicle: 1984 Ford F250 Pickup	Impact speed: 92.2 km/h (57.3 mi/h)
Test inertia weight: 2452 kg (5400 lb)	Impact angle: 20.6 degrees
Gross static weight: 2528 kg (5568 lb)	

The vehicle impacted the bridge railing between posts 3 and 4 (post 1 was the first post at the upstream end of the bridge railing) or 0.3 m (12 in) downstream from post 3. The vehicle was traveling parallel to the bridge railing at a speed of 82.5 km/h (51.3 mi/h). The vehicle lost contact with the bridge railing traveling at a speed of 78.2 km/h (48.6 mi/h) and at an exit angle of 2.2 degrees. The brakes on the vehicle were applied and the vehicle subsequently came to rest 77.0 m (252.5 ft) down from and 3.7 m (12 ft) behind of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 49.

The bridge railing received only cosmetic damage. However, the curb section and bridge deck sustained structural damage at the two posts immediately upstream and downstream of the point of impact (posts 3 and 4). It appears from the damage patterns that the curb section and bridge deck failed under the combination of bending and shear forces (principally shear), as evidenced by the 45-degree cracks starting at the anchor bolts. This suggested that there might not be sufficient concrete cover and steel reinforcement around the anchorage bolts to resist the forces acting on the post and anchorage assembly during impact. The vehicle was in contact with the bridge railing for a total length of 6.1 m (19.9 ft).

The vehicle sustained damage to the right side. Maximum crush at the right front corner at bumper height was 254 mm (10.0 in) and there was 25 mm (1.0 in) of crush at the right A pillar. The wheelbase on the right side was shortened by 32 mm (1.75 in). The tie rod and right radius arm were damaged. Also, damage was done to the front bumper, hood, grill, right front fender, right front rim, right door, right rear bumper, and right rear tire and rim.



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-19
Date	07/22/93
Test Article	
Type	Bridge Rail
	NETC Bridge Rail
Installation Length (m)	30.5 (100 ft)
Size and/or Dimension and Material of Key Elements	Tubular Steel Rail Elements on W6 X 25 Steel Posts @ 2.4 m on 241-mm Curb
Soil Type and Condition	Concrete Bridge Deck, Dry
Test Vehicle	
Type	Production Model
Designation	2000 P
Model	1984 Ford F250 Pickup
Mass (kg) Curb	1980 (4361 lb)
Test Inertial	2452 (5400 lb)
Dummy	76 (168 lb)
Gross Static	2528 (5568 lb)

Impact Conditions	
Speed (km/h)	92.2 (57.3 mi/h)
Angle (deg)	20.6
Exit Conditions	
Speed (km/h)	78.2 (48.6 mi/h)
Angle (deg)	2.2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.7 (12.2 ft/s)
y-direction	6.6 (21.5 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-2.5
y-direction	-12.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-3.4
y-direction	-10.3
z-direction	-2.4

Test Article Deflections (mm)	
Dynamic	Not Available
Permanent	6 (0.25 in)
Vehicle Damage	
Exterior	
VDS	01RFQ-3
CDC	01FREK2
	03RDES1
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	254 (10.0 in)
Max. Occ. Compart. Deformation (mm)	25 (1.0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	26
Max. Pitch Angle (deg)	-5
Max. Yaw Angle (deg)	-25

Figure 49. Summary of results for test 471470-19.

10.4 TEST NUMBER 471470-29 (AASHTO PL-2 SINGLE-UNIT TRUCK TEST)

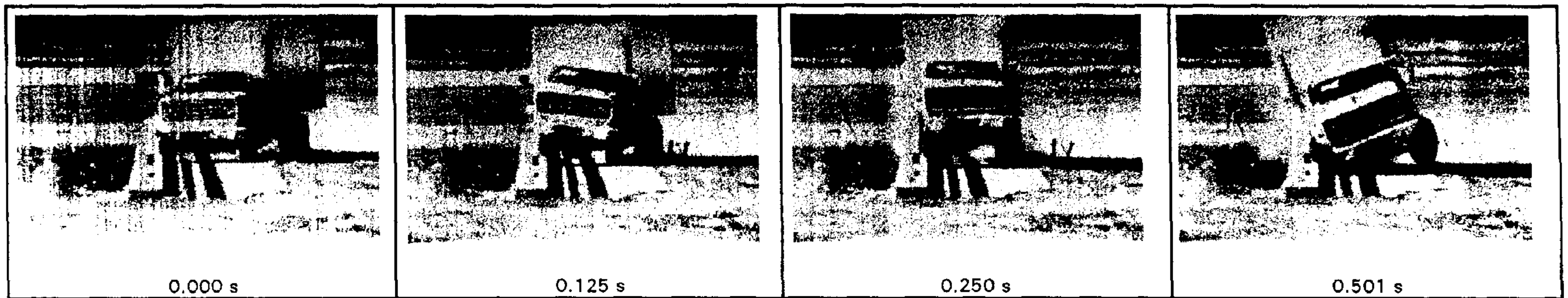
Test vehicle: 1980 GMC 6000 truck	Impact speed: 81.7 km/h (50.8 mi/h)
Test inertia weight: 5574 kg (12 278 lb)	Impact angle: 15.5 degrees
Gross static weight: 8000 kg (17 636 lb)	

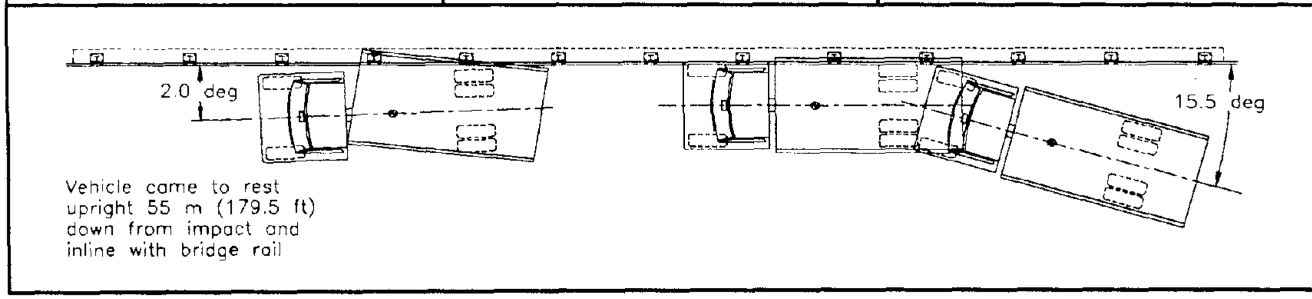
As discussed previously, some revisions were made to the design details for the bridge deck, curb section, and the steel reinforcement since the curb section and bridge deck sustained structural damage at the two posts immediate upstream and downstream of the point of impact in the pickup truck redirection test (test no. 471470-19). The redesigned bridge deck and curb section were constructed and evaluated in this crash test.

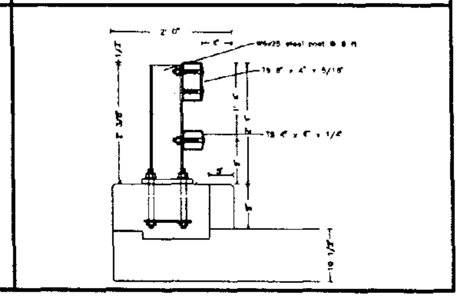
The target impact point was midspan between posts 4 and 5. However, the vehicle drifted to the right after release from the guidance system and the vehicle impacted the bridge rail 152 mm (6 in) downstream of post 4. The right front corner of the vehicle bumper contacted the rail and the right front tire contacted the curb simultaneously at the time of impact. Redirection of the vehicle began and shortly after, the right front tire began to climb up the face of the curb, reaching the top. The right front corner of the vehicle contacted the top of post 5, the left front tire became airborne and the right rear tire aired out. The vehicle became parallel with the installation traveling at 76.4 km/h (47.5 mi/h). The rear of the vehicle contacted the bridge rail, and the right front corner of the vehicle reached post 6; however, there was no direct contact with the post. The right front corner of the box contacted the top of the upper rail element. The cab of the vehicle reached a maximum clockwise roll of 26 degrees and began to roll counterclockwise while the box was still rotating clockwise. The box became partially separated from the frame of the vehicle and the box rode along the top of the rail. The vehicle rode off the end of the rail at an exit angle of approximately 2.0 degrees toward the bridge rail. The vehicle brakes were applied as the vehicle exited the test area, and subsequently came to rest 55 m (180 ft) downstream from the point of impact and parallel with the installation. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 50.

There were tire marks and gouges on the face of the rail and curb. The length of contact with the curb was 5.5 m (18.0 ft) and length of the initial contact with the rail element was 4.3 m (14.0 ft). The box of the truck was in contact with the upper part of the rail from post 8 to the end of the test installation, with tire marks on the face of the rail between posts 8 and 10. The bolts on the lower rail at posts 3, 4, and 5 were sheared off.

Maximum exterior crush at the right front corner of the vehicle was 120 mm (4.7 in) and there was no deformation or intrusion into the occupant compartment. The right-side spring U-bolts were damaged and the right front tire and wheel were pushed rearward into the fuel tank. The box was partially separated from the frame and shifted to the right. The bumper, hood, right front quarter panel, and right door also were damaged.







General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-29
Date	12/08/94
Test Article	
Type	Bridge Rail
Name or Manufacturer	NETC Bridge Rail
Installation Length (m)	30.5 m (100 ft)
Size and/or Dimension and Material of Key Elements	Tubular Steel Rail Elements on W6x25 Steel Post @ 2.4 m on 241 mm curb
Soil Type and Condition	Concrete Bridge Deck, Dry
Test Vehicle	
Type	Single-Unit Truck
Designation	8000S
Model	1980 GMC 6000
Mass (kg) Curb	5574 (12 278 lb)
Test Inertial	8000 (17 621 lb)
Dummy	N/A
Gross Static	8000 (17 621 lb)

Impact Conditions	
Speed (km/h)	81.7 (50.8 mi/h)
Angle (deg)	15.5
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	2.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	2.3 (7.5 ft/s)
y-direction	3.6 (12.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.0
y-direction	-3.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-1.8
y-direction	-2.6
z-direction	3.5

Test Article Deflections (m)	
Dynamic	nil
Permanent	nil
Vehicle Damage	
Exterior	
VDS	01RFQ2
CDC	01FRLK1 & 01RFEW2
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	120 (4.7 in)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	19
Max. Pitch Angle (deg)	-6
Max. Yaw Angle (deg)	-16

Figure 50. Summary of results for test 471470-29.

10.5 SUMMARY OF FINDINGS

For the small car redirection test (test no. 471470-18), the NETC bridge rail is considered to have successfully met all evaluation criteria set forth in both the 1989 AASHTO *Guide Specifications for Bridge Railings* and NCHRP Report 350, summaries of which are shown in tables 22 and 23, respectively. The bridge railing contained and smoothly redirected the test vehicle. The bridge railing received only cosmetic damage with minimal lateral movement of the bridge railing and posts. There were no debris or detached elements from the bridge railing that could potentially intrude into the occupant compartment or pose undue hazard to adjacent traffic. The vehicle remained upright and stable during the collision sequence. The lateral occupant impact velocity of 8.4 m/s (27.5 ft/s) was slightly higher than the specified limit of 7.6 m/s (25 ft/s) according to the Guide Specifications. However, it should be noted that the impact speed and angle of 100.9 km/h (62.7 mi/h) and 20.6 degrees were also slightly higher than the nominal impact speed and angle of 96.5 km/h (60 mi/h) and 20 degrees. If the impact angle and speed are normalized, the lateral occupant impact velocity would fall below the specified limit of 7.6 m/s (25 ft/s). Furthermore, the occupant impact velocity of 8.4 m/s (27.5 ft/s) was less than the preferred limit of 9.0 m/s (29.5 ft/s) recommended under NCHRP Report 350. The longitudinal occupant impact velocity and occupant ridedown accelerations were well within the specified limits. Velocity change of the vehicle during the collision was 12.2 km/h (7.6 mi/h). The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

In the pickup truck redirection test (test no. 471470-19), the bridge rail also successfully met all evaluation criteria set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings* and NCHRP Report 350, summaries of which are shown in tables 24 and 25, respectively. The bridge railing contained and smoothly redirected the test vehicle. The bridge railing received only minor damage; however, there were stress cracks at the two posts immediately upstream and downstream of the point of impact (posts 3 and 4), starting at the anchor bolts and propagating through the curb section and the bridge deck. There were no debris or detached elements from the bridge railing that could potentially intrude into the occupant compartment or pose undue hazard to adjacent traffic. The vehicle remained upright and stable during the collision sequence. The occupant impact velocities and occupant ridedown accelerations for this test are well within the specified limits set forth in the Guide Specifications and NCHRP Report 350. Velocity change of the vehicle during the collision was 14.0 km/h (8.7 mi/h). The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes. The impact speed of 92.2 km/h (57.3 mi/h) was lower than the specified speed of 96.5 km/h (60 mi/h). However, given the good impact performance of the bridge railing, it was judged that the bridge railing would have performed satisfactorily had the impact speed been at the specified impact speed.

As mentioned above, the curb section and bridge deck sustained structural damage at the two posts immediately upstream and downstream of the point of impact in the pickup truck redirection test (test no. 471470-19). Consequently, the design details for the bridge deck, curb section, and steel reinforcement were revised to provide more anchorage capacity.

Table 22. Assessment of results of test 471470-18 on NETC bridge rail (according to 1989 AASHTO Guide).

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a. The test 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.	The vehicle was contained.	Pass
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.	There was no debris to penetrate the occupant compartment or present undue hazard to other traffic.	Pass
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was no deformation or intrusion into the occupant compartment.	Pass
d. The vehicle shall remain upright during and after collision.	The vehicle remained upright.	Pass
e. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .07 — Good	Pass
g. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30) — Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15 — Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 5.2 (16.9) — Lateral 8.4 (27.5) Occupant Ridedown Accelerations - g's Longitudinal -1.6 — Lateral -6.8	Fail Pass
h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (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 6 m (20 ft) from the line of the traffic face of the railing.	Exit angle was 2.2 degrees. The vehicle came to rest 65 m (212 ft) down and 1 m (3 ft) forward of the point of impact.	Pass

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

Table 23. Assessment of results of test 471470-18 on NETC bridge rail (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute — Test No.: 471470-18 — Test Date: 07/20/93

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The bridge rail contained and redirected the vehicle.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was no debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during and after the collision.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Longitudinal Occupant Impact Velocity = 5.2 m/s (16.9 ft/s) Lateral Occupant Impact Velocity = 8.4 m/s (27.5 ft/s)	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Longitudinal Ridedown Acceleration = -1.6 g's Lateral Ridedown Acceleration = -6.8 g's	Pass
<u>Vehicle Trajectory</u>		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Exit angle was 2.2 degrees. Vehicle came to rest 65 m (212 ft) down from and 1 m (3 ft) forward of point of impact.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle was less than 60 percent of the test impact angle.	Pass

Table 24. Assessment of results of test 471470-19 on NETC bridge rail (according to 1989 AASHTO Guide).

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a. The test 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.	The vehicle was contained.	Pass
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.	There was no debris to penetrate the occupant compartment or present undue hazard to other traffic.	Pass
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	There was minimal deformation (13 mm (0.5 in)) into the occupant compartment.	Pass
d. The vehicle shall remain upright during and after collision.	The vehicle remained upright.	Pass
e. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .12 — Good	Pass
g. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal: 9.2 (30) — Lateral: 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal: 15 — Lateral: 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal: 3.7 (12.2) — Lateral: 6.6 (21.5) Occupant Ridedown Accelerations - g's Longitudinal: -2.5 — Lateral: -12.2	Pass Pass
h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 30 m (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 6 m (20 ft) from the line of the traffic face of the railing.	Exit angle was 2.2 degrees. The vehicle came to rest 77 m (252 ft) down and 4 m (12 ft) behind the point of impact.	Pass

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

Table 25. Assessment of results of test 471470-19 on NETC bridge rail (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute | Test No.: 471470-19 | Test Date: 07/22/93

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The bridge rail contained and redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was no debris to show potential for penetration of the occupant compartment or to present undue hazard to other traffic. There was minimal deformation (13 mm (0.5 in)) into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	Exit angle was 2.2 degrees. Vehicle came to rest 77 m (252 ft) down from and 4 m (12 ft) behind the point of impact.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 3.7 m/s (12.2 ft/s) Longitudinal Ridedown Acceleration = -1.2. g's	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Exit angle was less than 60 percent of the test impact angle.	Pass

The test installation with the revised bridge deck and curb section was constructed and crash tested in the single-unit truck redirection test (test no. 471470-29). The NETC bridge rail met all evaluation criteria set forth both in the 1989 AASHTO *Guide Specifications for Bridge Railings* and NCHRP Report 350, summaries of which are shown in tables 26 and 27, respectively. The bridge railing contained and smoothly redirected the test vehicle. The bridge railing received moderate damage, but there was no structural damage to the bridge deck and curb section, indicating that the design modifications worked as intended. There were tire marks and gouges on the face of the rail and the curb section and the bolts on the lower rail sheared off at posts 3, 4, and 5. There were no debris or detached elements from the bridge railing that could potentially intrude into the occupant compartment or pose undue hazard to adjacent traffic. The vehicle remained upright and stable during the collision sequence. The occupant impact velocities and occupant ridedown accelerations for this test are well within the specified limits set forth in the Guide Specifications and NCHRP Report 350. Velocity change of the vehicle during the collision was 14.0 km/h (8.7 mi/h). The vehicle trajectory at loss of contact indicates minimal potential for intrusion into adjacent traffic lanes.

In summary, the revised NETC bridge rail and deck design met all evaluation criteria for a Performance Level 2 (PL-2) bridge railing set forth in the 1989 AASHTO *Guide Specifications for Bridge Railings* and test level 4 (TL-4) conditions in NCHRP Report 350.

Table 26. Assessment of results of test 471470-29 on NETC bridge rail (according to 1989 AASHTO Guide).

AASHTO EVALUATION CRITERIA*	TEST RESULTS	ASSESSMENT
a. The test 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.	Vehicle was contained. There was no measurable deflection of the metal rail elements.	Pass
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.	There were no detached elements or other debris to penetrate or show undue hazard to other traffic.	Pass
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	No deformation occurred to the occupant compartment.	Pass
d. The vehicle shall remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
e. The test article must smoothly redirect the vehicle.	The vehicle was smoothly redirected.	Pass
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction, μ: μ — Assessment 0 - .25 — Good .26 - .35 — Fair >.35 — Marginal where $\mu = (\cos\theta - V_p/V)/\sin\theta$	μ — Assessment .11 — Good	Pass
g. The impact velocity shall be less than: Occupant Impact Velocity - m/s (ft/s) Longitudinal 9.2 (30); Lateral 7.6 (25) Occupant Ridedown Accelerations - g's Longitudinal 15; Lateral 15	Occupant Impact Velocity - m/s (ft/s) Longitudinal 2.3 (7.5); Lateral 3.6 (12.0) Occupant Ridedown Accelerations - g's Longitudinal -4.0; Lateral -3.2	N/A
h. Vehicle exit angle from the barrier shall not be more than 12 degrees.	Exit angle was approximately 2 degrees toward the bridge rail.	Pass

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

Table 27. Assessment of results of test 471470-29 on NETC bridge rail (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute | Test No.: 471470-29 | Test Date: 12/08/94

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The test article contained and redirected the vehicle with no measurable deflection of the metal rail elements.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to penetrate or show potential hazard to others. There was no deformation or intrusion into the occupant compartment.	Pass
G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	The vehicle remained upright during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle rode off the end of the bridge rail at an approximate yaw of 2 degrees toward the bridge rail.	Pass

XI. MINI-MELT FOR W-BEAM, WEAK-POST (G2) GUARDRAIL SYSTEM

The turned-down terminal is typically used with the W-beam, weak-post (G2) guardrail system in current designs. However, the FHWA, in a memorandum dated June 28, 1990, from the Director of the Office of Highway Safety to the Regional Federal Highway Administrators,(7) has indicated that:

- Turned-down terminals should not be used on new installations of guardrails for freeway, expressway, or other high-speed, high-volume facilities.
- Safety improvement projects, hazard elimination projects, or 3R/4R projects on high-speed, high-volume facilities should require replacement of turned-down terminals with approved terminals.
- Use of turned-down terminals on projects involving high-speed, but moderate traffic-carrying facilities should be considered on a case-by-case basis or an approved State developed policy.
- Use of turned-down terminals on low-speed or any low-volume facility may be allowed based on reasonable risk management considerations.

With the discontinued use of the turned-down terminal for guardrails on high-speed, high-volume facilities, an alternate terminal design is necessary for both new installations and replacement or retrofit of existing installations. A number of FHWA-approved terminal designs are currently available, such as the Modified Eccentric Loader Terminal (MELT), the Slotted Rail Terminal (SRT), and the ET-2000. However, these terminals are designed for use with strong-post W-beam guardrail (G4) systems, and their performance with the W-beam, weak-post (G2) guardrail system is yet to be evaluated.

The FHWA has designed a terminal specifically for use with the W-beam, weak-post (G2) guardrail system that is based on the same concept as the MELT (hereinafter referred to as the Mini-MELT). A series of four crash tests were conducted to evaluate the Mini-MELT, the results of which are presented in this chapter. The first crash test was conducted and evaluated in accordance with guidelines set forth in NCHRP Report 350. The remaining three crash tests were conducted and evaluated in accordance with guidelines set forth in NCHRP Report 230.

11.1 TEST INSTALLATION

Three different designs of the Mini-MELT were evaluated in the four crash tests. Thus, there were a total of three different test installations. The initial design was evaluated in the first crash test (test no. 471470-20), which failed to perform satisfactorily. The design was modified and evaluated in the second crash test (test no. 471470-23), which also failed to perform satisfactorily. The design was revised again and successfully tested in the third and fourth crash tests (test nos. 471470-24 and 25).

For the first crash test (test no. 471470-20), the test installation consisted of a 22.9-m- (75-ft-) long section of a standard W-beam, weak-post (G2) guardrail system with a Mini-MELT at each of the two ends, for a total length of 53 m (175 ft), as shown in figure 51. For the second and third test installations and the next three crash tests (test nos. 471470-23, 24, and 25), the test installation consisted of 53 m (175 ft) of the standard G2 guardrail system with a Mini-MELT installed at one end and a turned-down end terminal at the opposite end, for a total length of 76 m (250 ft). Photographs of this installation are shown in figure 52.

The standard W-beam, weak-post (G2) guardrail system consisted of 1.6-m- (5-ft, 3-in-) long S3×5.7 posts with 203-mm × 610-mm × 6-mm (8-in × 24-in × 1/4-in) soil plates, spaced 3.8 m (12 ft, 6 in) center to center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. The height of the guardrail to the top of the W-beam rail element was 762 mm (30 in). The W-beam rail elements were attached to the posts with 7.94-mm- (5/16-in-) diameter bolts and square plate washers. Also, 12.7-mm- (1/2-in-) diameter, 38.1-mm- (1-1/2-in-) long shelf bolts were attached to the posts with two or more nuts for the W-beam rail elements to rest on. The purpose of the shelf bolts is to reduce the loading on the 7.94-mm- (5/16-in-) diameter post bolts from the weight of the W-beam rail elements and other dead loads, such as snow and ice on the rail elements.

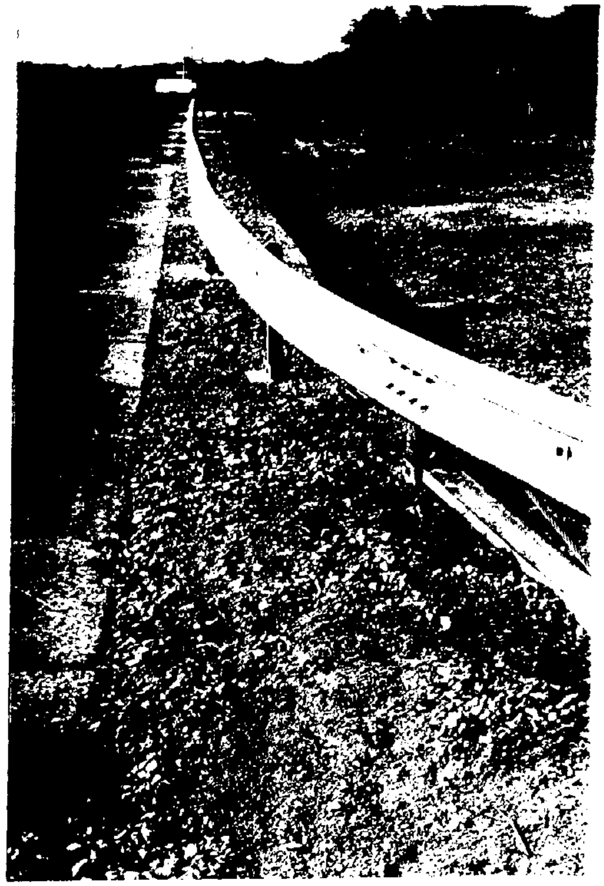
Descriptions of the three different designs of the Mini-MELT are presented in the following sections.

11.1.1 Mini-MELT Design for First Crash Test (Test No. 471470-20)

Figure 53 shows details of the initial Mini-MELT design as tested in the first crash test (test no. 471470-20). Photographs of the terminal are shown in figure 54. The Mini-MELT had a total length of 15.2 m (50 ft), consisting of two 1.9-m- (6-ft, 3-in-) spans at the end of the terminal, followed by three 3.8-m (12-ft, 6-in) spans. The height to the top of the buffered nose piece was 635 mm (25 in) compared with 762 mm (30 in) for the standard G2 guardrail system. The reduction in height was effected gradually through the first three posts with drops of 165, 127, and 76.2 mm (6.5, 5.0, and 3.0 in) for posts 1, 2, and 3, respectively.

The end of the terminal was flared 1.22 m (4 ft) from the tangent section of the guardrail and the parabolic flare was effected over the first 11.4 m (37 ft, 6 in), with offsets of 1.22, 0.63, 0.34, and 0.055 m (4.0, 2.08, 1.13, and 0.18 ft) for posts 1, 2, 3, and 4, respectively. Note that the first two 3.8-m (12-ft, 6-in) sections of W-beam rail elements were shop curved to accommodate the parabolic curve, with a nominal radius of 11.6 m (38 ft) for the first section and 27.4 m (90 ft) for the second section.

The buffered nose piece had two bolted-on diaphragms similar to the standard MELT buffered nose piece. Posts 1 and 2 were modified breakaway wooden posts (BWPs) installed in 1525-mm- (5-ft-) long, TS 152-mm × 203-mm × 4.8-mm (6-in × 8-in × 3/16-in) steel



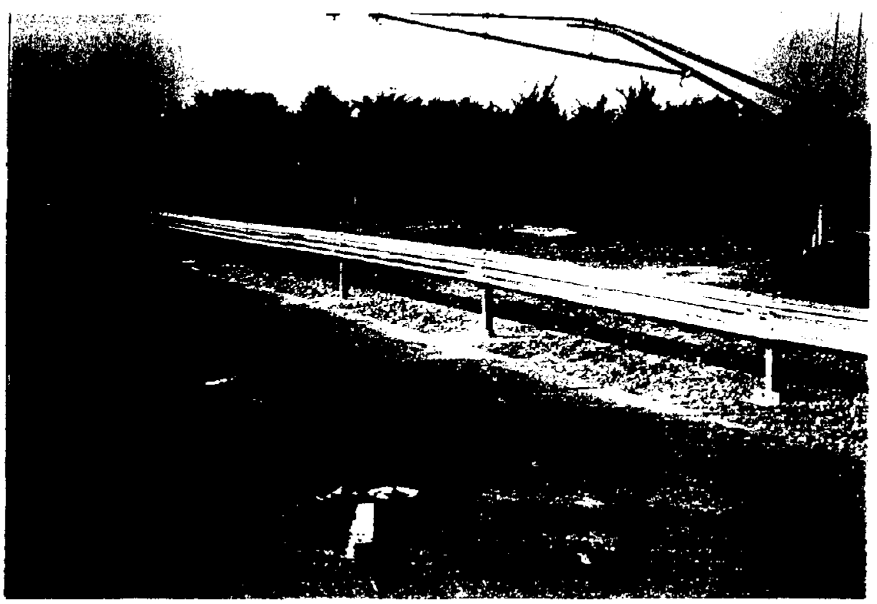


Figure 51. Mini-MELT used for test 471470-20.

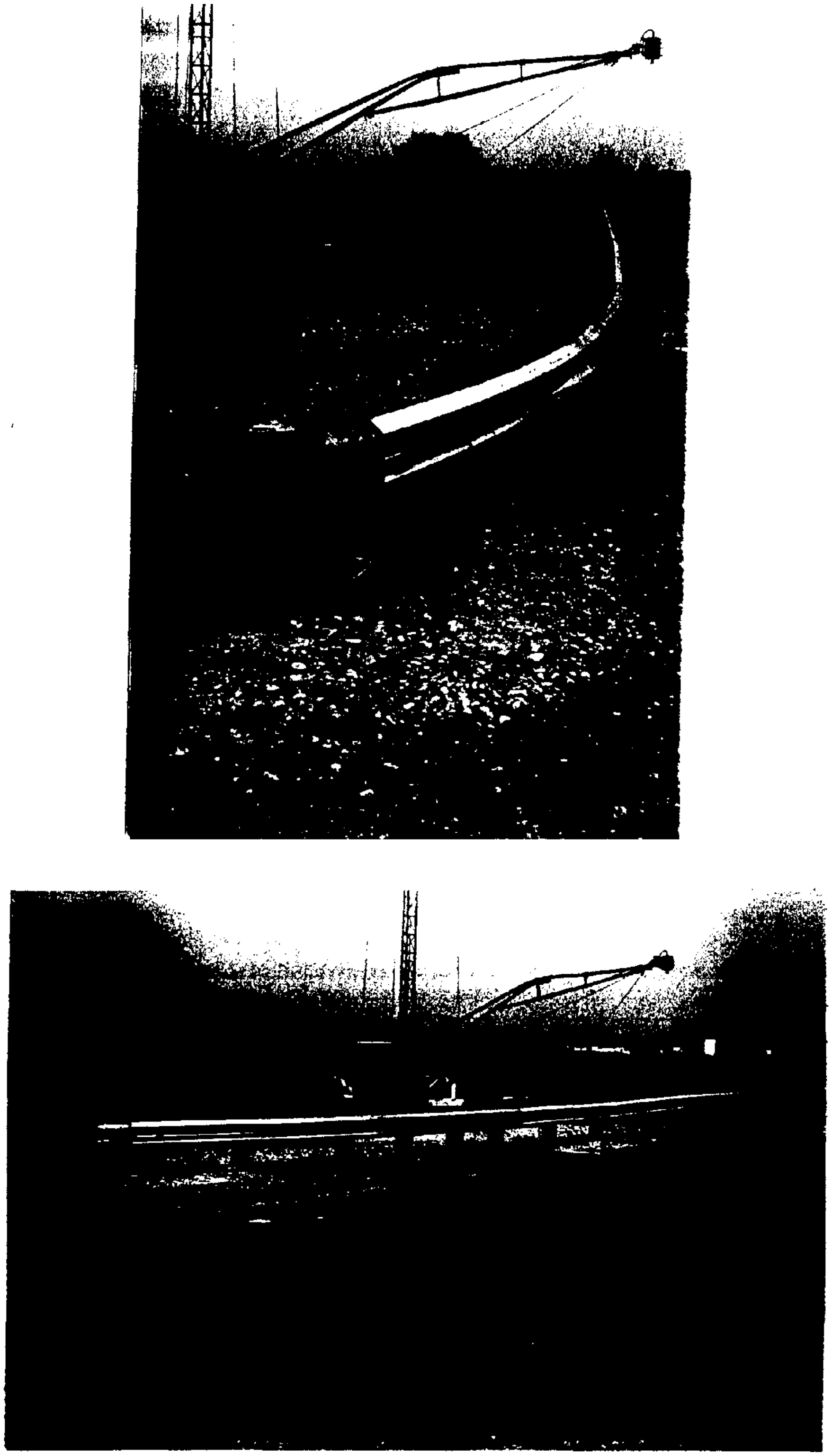


Figure 52. G2 guardrail with modified Mini-MELT before testing.

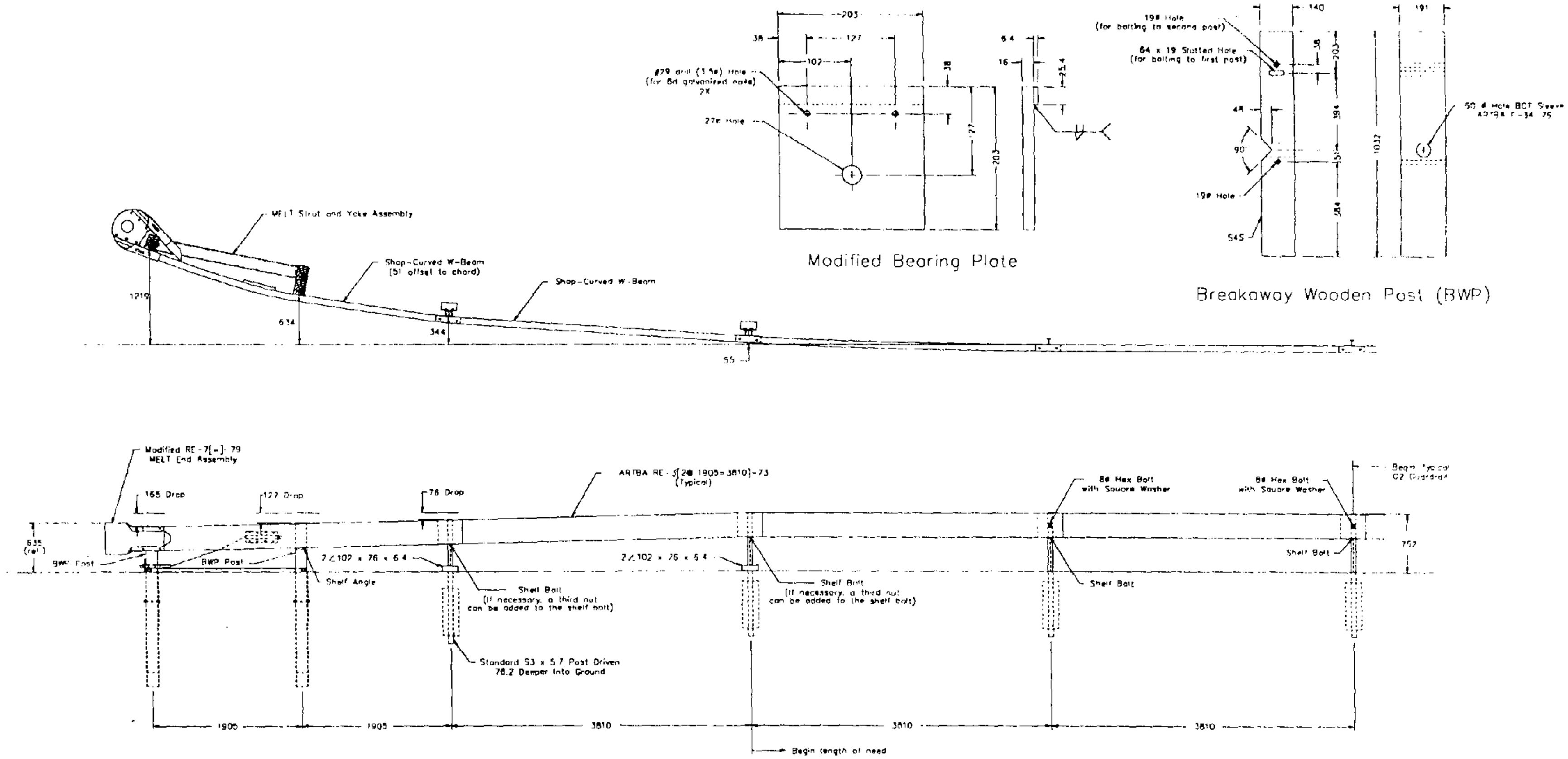


Figure 53. Schematic of the Mini-MELT.

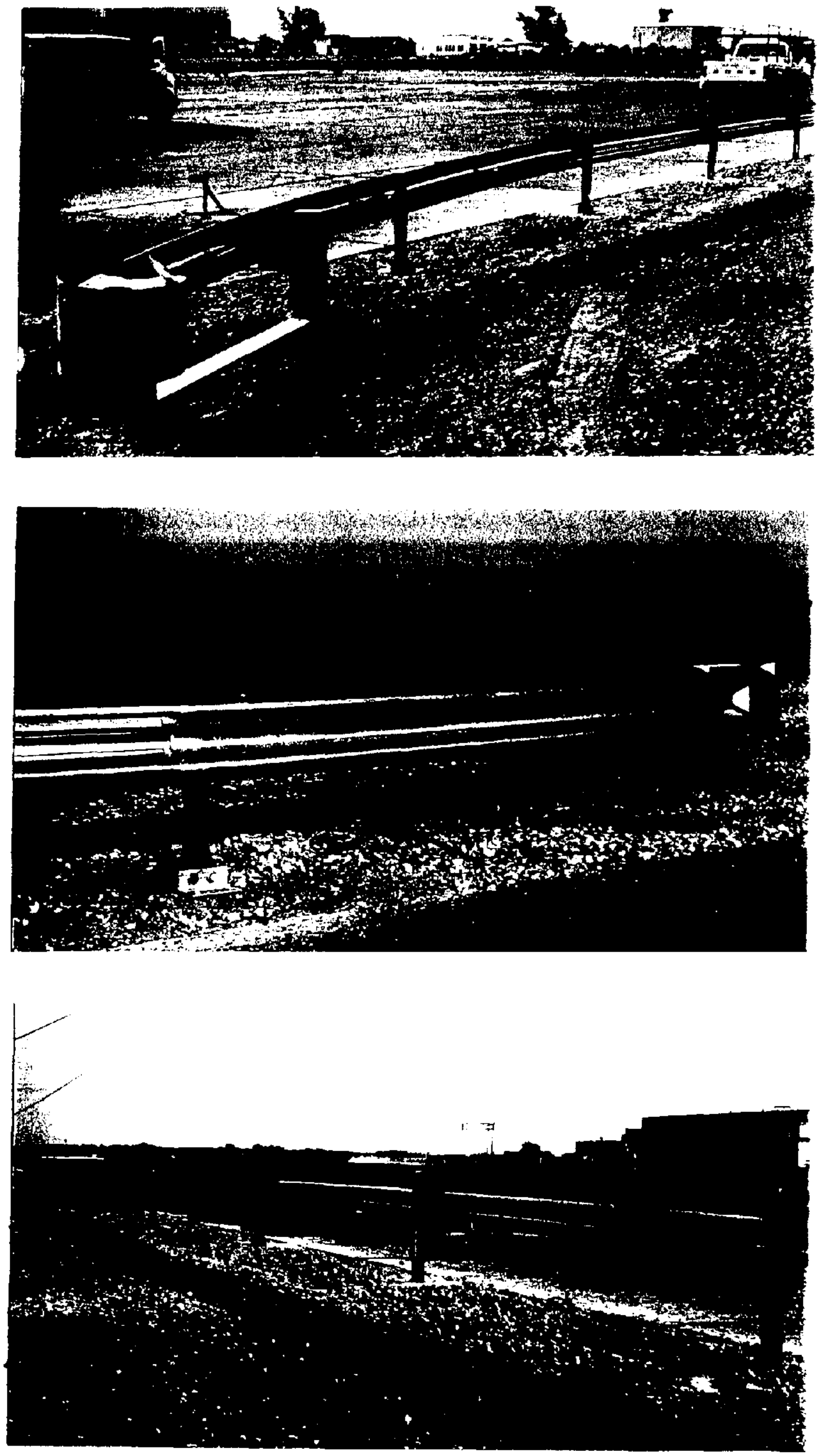


Figure 54. Mini-MELT before test 471470-20.

foundation tubes with 460-mm × 610-mm × 6-mm (18-in × 24-in × 1/4-in) soil plates. A 160-mm × 50-mm (6-in × 2-in) channel strut connected the two foundation tubes at ground level for increased anchorage capacity.

The modified BWPs were 1.03 m (3 ft, 4-5/8 in) long, 140 mm × 191 mm (5-1/2 in × 7-1/2 in) in cross-sectional dimensions with a 60.3-mm- (2-3/8-in-) diameter hole drilled through the post at ground level to facilitate breaking of the posts upon impact. The modified BWP was further weakened by cutting a 90-degree, 47.6-mm- (1-7/8-in-) deep notch into the post at the drilled hole on the front face of the post. The post bolt hole of the first BWP (i.e., end post) was slotted with the dimensions of 19.1 mm × 63.5 mm (3/4 in × 2-1/2 in). The second BWP was not bolted to the W-beam rail element, but rested on a shelf angle attached to the post through a second 19.1-mm- (3/4-in-) diameter hole. The bearing plate for the cable anchor was modified with two drilled 3.45-mm- (0.136-in-) diameter holes spaced 127 mm (5 in) apart and 38.1 mm (1-1/2 in) from the top to allow attachment of the bearing plate to the end BWP with galvanized nails. Photographs of the details for posts 1 and 2 are shown in figure 55.

Standard 1.6-m- (5-ft, 3-in-) long S3×5.7 steel posts with 203-mm × 610-mm × 6-mm (8-in × 24-in × 1/4-in) soil plates were used starting at post 3. Note that post 3 was driven 76.2 mm (3.0 in) deeper into the ground because of the reduced height mentioned previously. Two 102-mm × 76.2-mm × 6.35-mm (4-in × 3-in × 1/4-in) angles, one in front of and one behind the post, were clamped onto posts 3 and 4 to reduce rotation of these posts. The W-beam rail elements were not bolted onto posts 3 and 4, but held in place by shelf bolts only. The W-beam rail elements were bolted to the posts starting at post 5. Photographs showing the details at posts 3 and 5 are shown in figures 56 and 57, respectively.

11.1.2 Mini-MELT Design for Second Crash Test (Test No. 471470-23)

The Mini-MELT design was revised because of the unsatisfactory performance in the first crash test. Figure 58 shows a schematic of the modified Mini-MELT as constructed and tested in the second crash test (test no. 471470-23). Photographs of the terminal are shown in figure 59. The modified Mini-MELT had a total length of 15.2 m (50 ft), consisting of two 1.9-m (6-ft, 3-in) spans at the end of the terminal, followed by three 1.3-m (4-ft, 2-in) spans, two 1.9-m (6-ft, 3-in) spans with wood posts, and a transition section of two 1.9-m (6-ft, 3-in) spans with steel posts. The height to the top of the W-beam rail element in the terminal section was 0.69 m (27 in), compared with 0.76 m (30 in) for the standard G2 guardrail system. The reduction in height was effected with a drop of 76.2 mm (3.0 in) over the 3.8-m (12-ft, 6-in) transition section just before the last wood post of the terminal.

The end of the terminal was flared 1.22 m (4 ft) from the tangent section of the guardrail and the parabolic flare was effected over the first 11.4 m (37-ft, 6-in) with offsets of 1.22, 0.63, 0.34, 0.20, 0.10, 0.06, and 0.024 m (4.0, 2.08, 1.16, 0.66, 0.33, 0.21, and 0.08 ft) for posts 1 through 6, respectively. Note that the first two 3.8-m (12-ft, 6-in) sections of

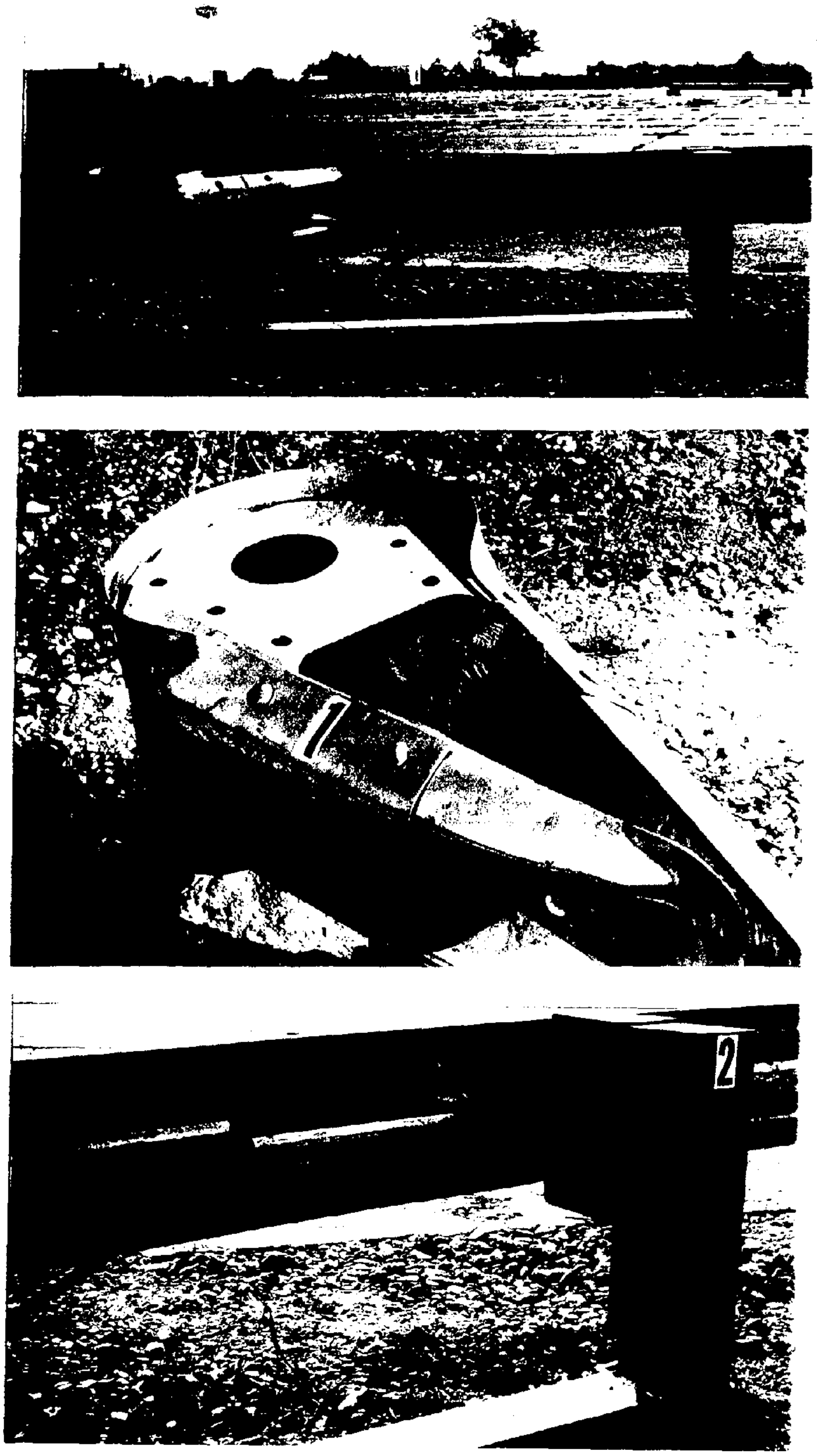


Figure 55. Mini-MELT posts 1 and 2 before test 471470-20.

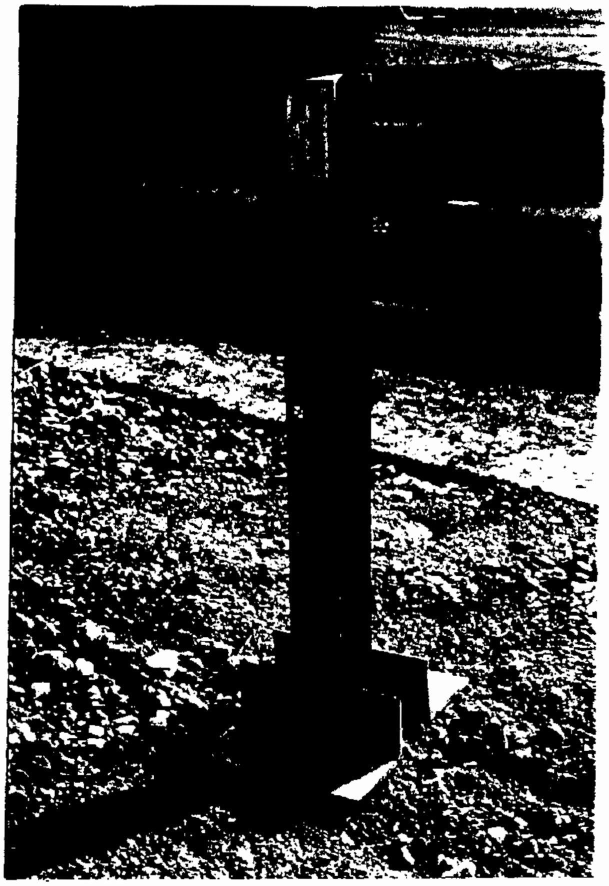


Figure 56. Mini-MELT post 3 before test 471470-20.

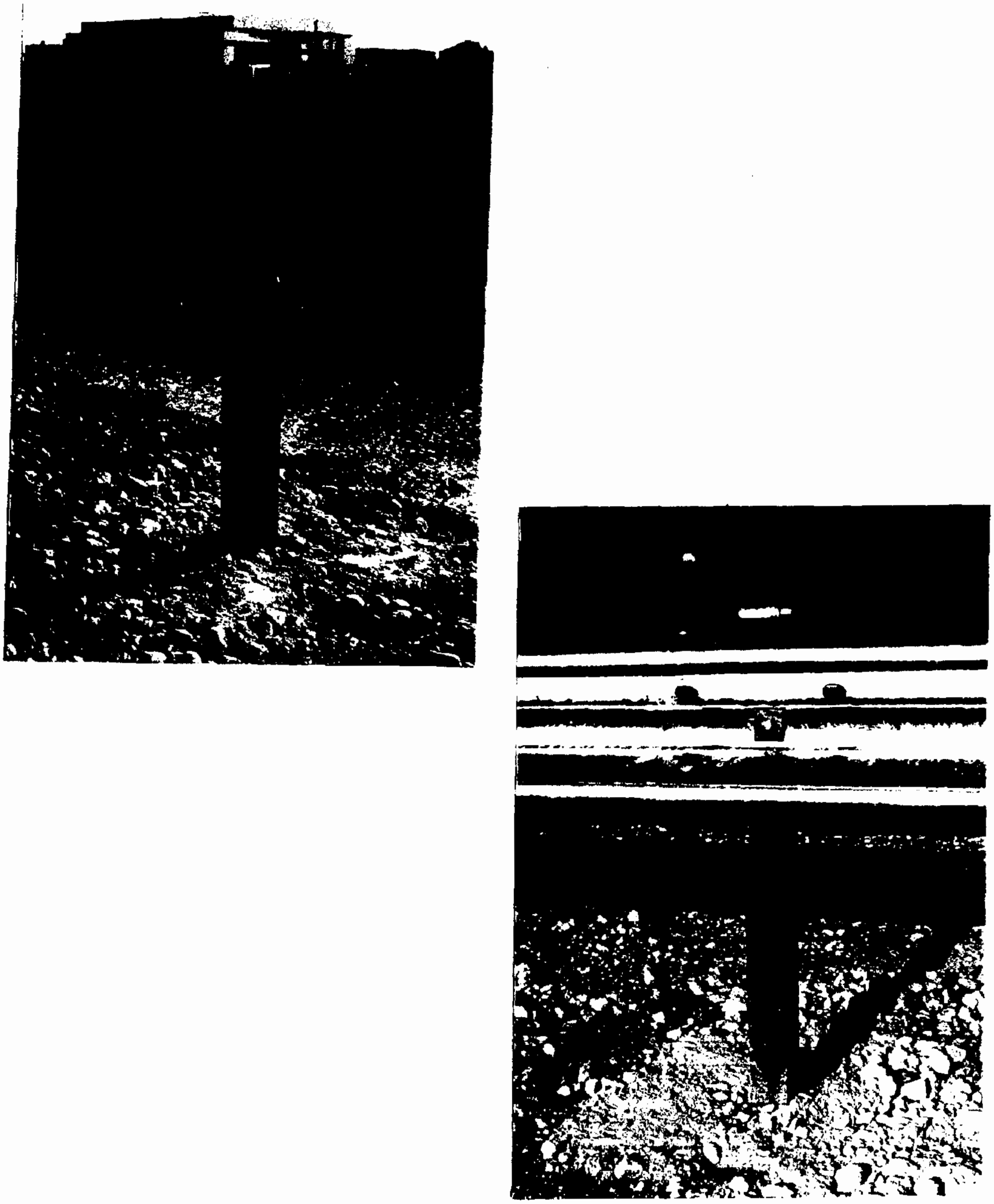


Figure 57. Mini-MELT post 5 before test 471470-20.

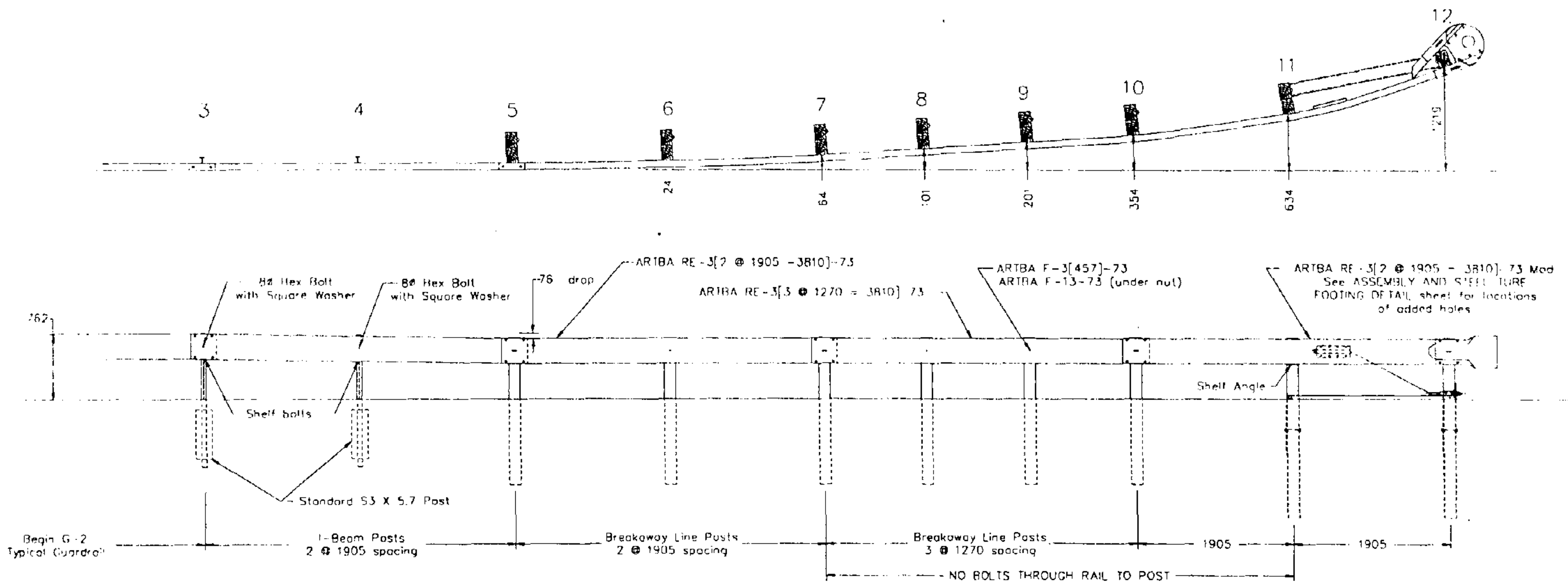


Figure 58. Schematic of the modified Mini-MELT used for test 471470-23.

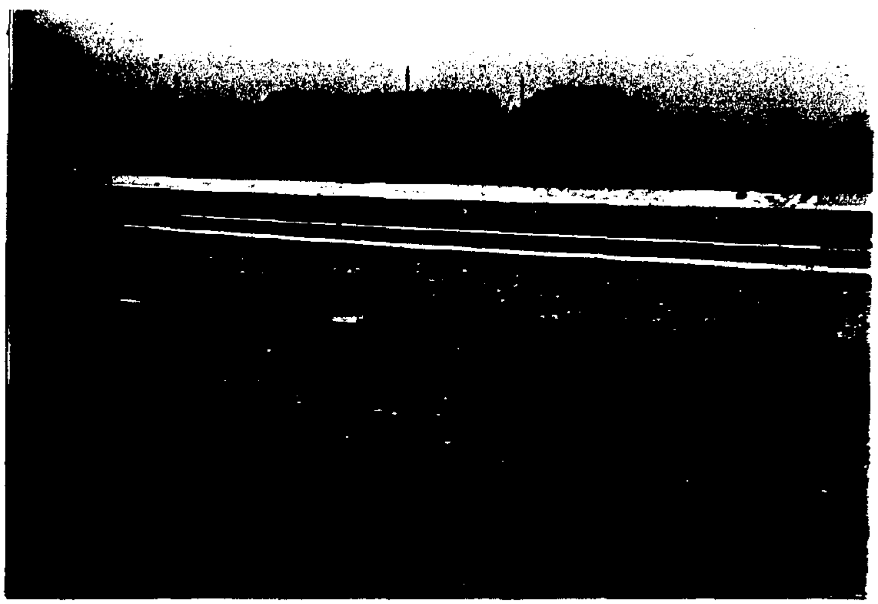


Figure 59. Modified mini-MELT used in test 471470-23.

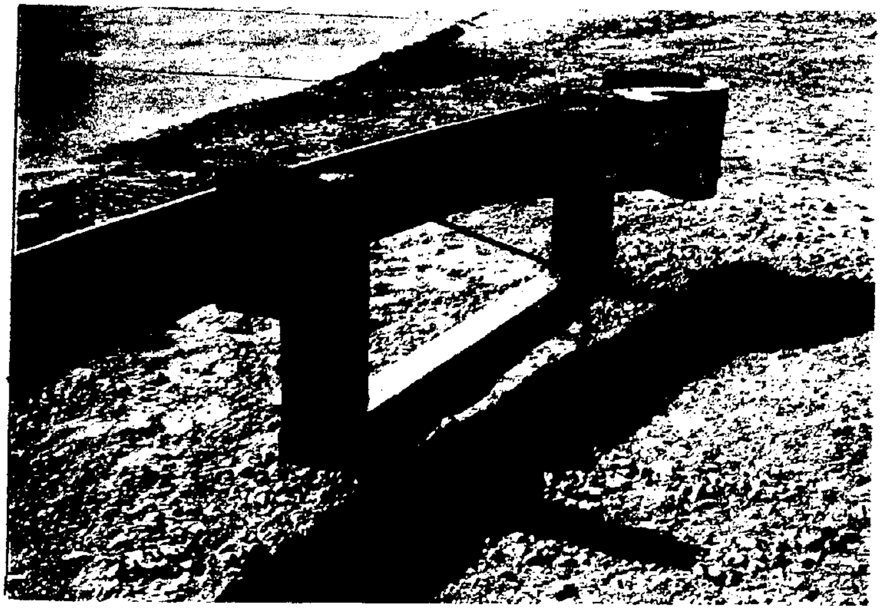
W-beam rail elements were shop curved to accommodate the parabolic curve, with a nominal radius of 11.6 m (38 ft) for the first section and 27.4 m (90 ft) for the second section.

The buffered nose piece had two bolted-on diaphragms similar to the standard MELT. Posts 12 (end post) and 11 were BWPs installed in 1525-mm- (5-ft-) long, TS 152-mm × 203-mm × 4.8-mm (6-in × 8-in × 3/16-in) steel foundation tubes with 460-mm × 610-mm × 6-mm (18-in × 24-in × 1/4-in) soil plates. A 160-mm × 50-mm (6-in × 2-in) channel strut connected the two foundation tubes at ground level for increased anchorage capacity. The posts were 1.1-m (43-in) long with cross-sectional dimensions of 140 mm × 191 mm (5-1/2 in × 7-1/2 in). A 60.3-mm- (2-3/8-in-) diameter hole was drilled through the post at ground level to facilitate breaking of the post upon impact. The post bolt hole of the end post (post 12) was slotted with the dimensions of 19.1 mm × 63.5 mm (3/4 in × 2-1/2 in). The second post (post 11) was not bolted to the W-beam rail element, but rested on a shelf angle attached to the post. The bearing plate for the cable anchor was modified with two 3.45-mm- (0.136-in-) diameter holes drilled 127 mm (5 in) apart and 38.1 mm (1-1/2 in) from the top to allow attachment of the bearing plate to the end post with galvanized nails. Photographs showing the details for posts 1 and 2 are shown in figure 60.

Posts 10 through 5 in the terminal section were 1.8-m- (6-ft-) long wooden Controlled Release Terminal (CRT) posts. The W-beam rail elements were not bolted onto posts 10 through 7. In other words, the W-beam rail elements were bolted at the end post (post 12) and then the next bolted post was post 6 for an unsupported rail length of 9.5 m (31 ft, 3 in). However, it should be noted that the rail element was supported by a shelf angle at the second post (post 11). Standard 1.6-m- (5-ft, 3-in-) long S3×5.7 steel posts with 203-mm × 610-mm × 6-mm (8-in × 24-in × 1/4-in) soil plates posts were then used starting at post 4 with two spans at 1.9 m (6 ft, 3 in) for the transition area, and then the standard 3.8-m (12-ft, 6-in) spacing throughout the remaining G2 guardrail system. Photographs showing the details at posts 10 through 4 are shown in figure 61.

11.1.3 Mini-MELT Design for Third and Fourth Tests (Test Nos. 471470-24 and 25)

The Mini-MELT design was further modified because of the unsatisfactory performance in the second crash test. Figure 62 shows a schematic of the modified Mini-MELT as constructed and tested. Photographs of the terminal are shown in figure 63. The modified mini-MELT had a total length of 26.6 m (87 ft, 6 in), consisting of two 1.9-m (6-ft, 3-in) spans at the end of the terminal, followed by three 1.3-m (4-ft, 2-in) spans, two 1.9-m (6-ft, 3-in) spans, and a 15.2-m (50-ft) transition section. The transition section consisted of eight 0.95-m (3-ft, 1-1/2-in) spans and then four 1.9-m (6-ft, 3-in) spans. The height to the top of the W-beam rail element in the terminal section was 0.69 m (27 in), compared with 0.76 m (30 in) for the standard G2 guardrail system. The reduction in height was effected with a drop of 76.2 mm (3.0 in) over the last two 1.9-m (6-ft, 3-in) spans before the 0.95-m (3-ft, 1-1/2-in) spaced spans.



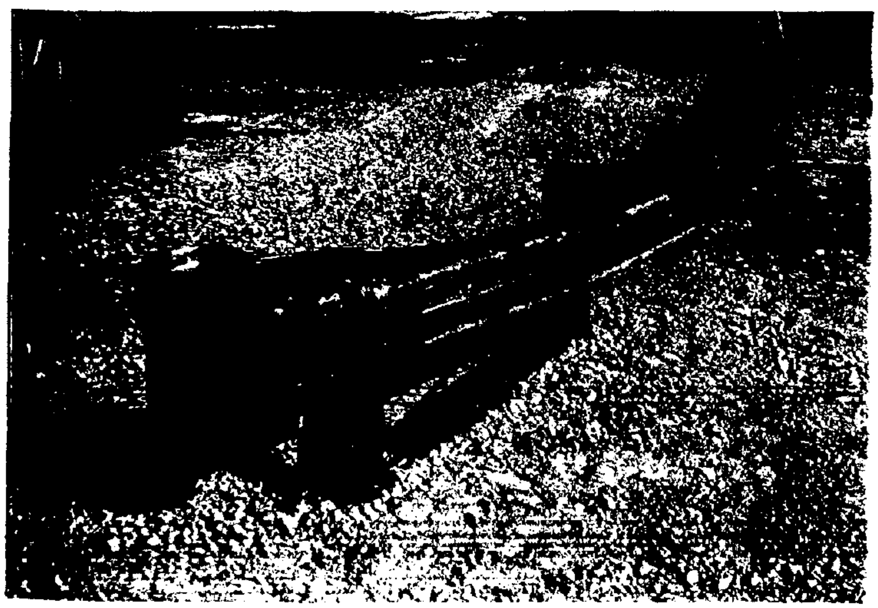
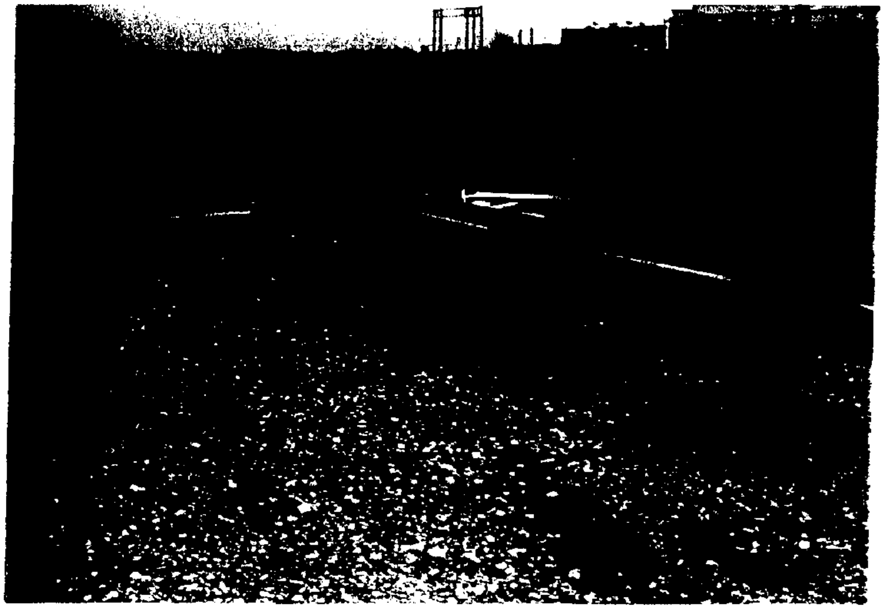


Figure 60. Modified mini-MELT posts 1 and 2 before test 471470-23.



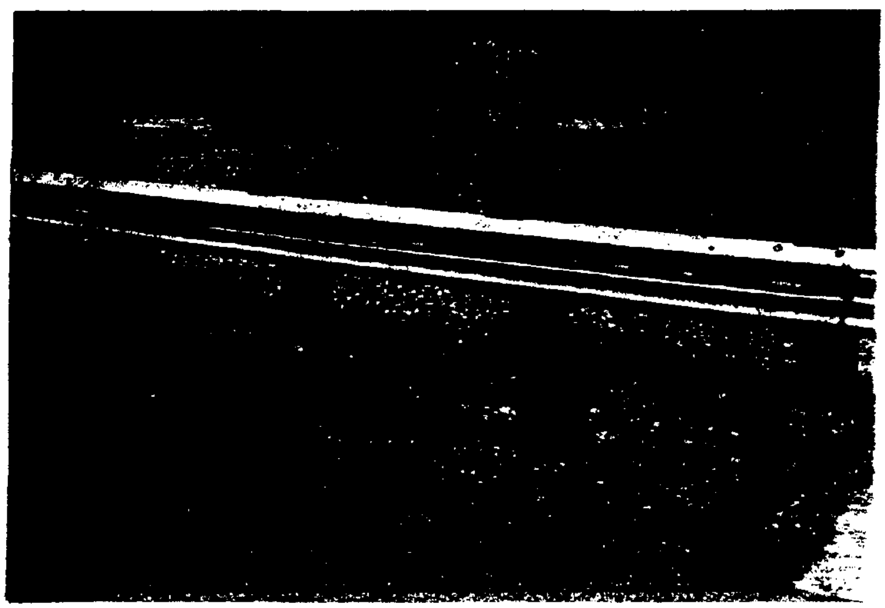


Figure 61. Posts 10 through 4 of the modified mini-MELT.

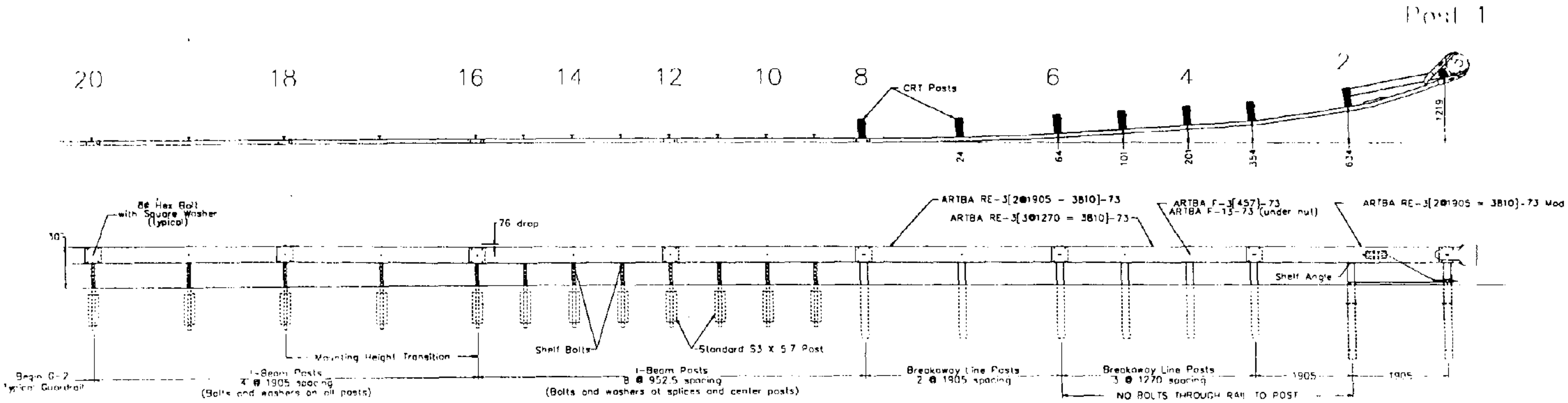


Figure 62. Details of the modified mini-MELT for the weak-post G2 guardrail system used for tests 471470-24 and 471470-25.

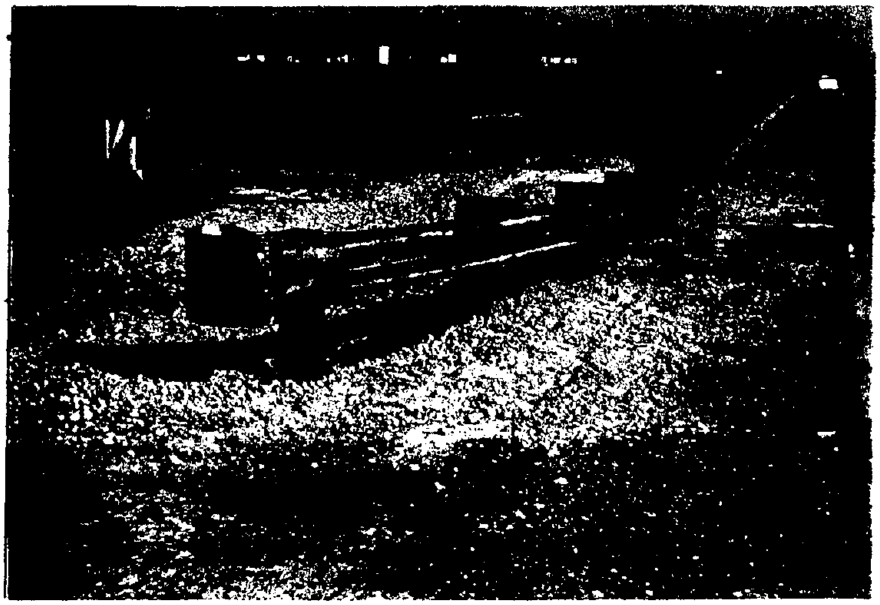


Figure 63. Modified mini-MELT used in tests 471470-24 and 471470-25.

The end of the terminal was flared 1.22 m (4 ft) from the tangent section of the guardrail and the parabolic flare was effected over the first 11.4 m (37 ft, 6 in), with offsets of 1.22, 0.63, 0.34, 0.20, 0.10, 0.06, and 0.024 m (4.0, 2.08, 1.16, 0.66, 0.33, 0.21, and 0.08 ft) for posts 1 through 8, respectively. Note that the first two 3.8-m (12-ft, 6-in) sections of W-beam rail elements were shop curved to accommodate the parabolic curve, with a nominal radius of 11.6 m (38 ft) for the first section and 27.4 m (90 ft) for the second section.

The buffered nose piece had two bolted-on diaphragms similar to the standard MELT. Posts 1 (end post) and 2 were BWPs installed in 1525-mm- (5-ft-) long, TS 152-mm × 203-mm × 4.8-mm (6-in × 8-in × 3/16-in) steel foundation tubes with 460-mm × 610-mm × 6-mm (18-in × 24-in × 1/4-in) soil plates. A 160-mm × 50-mm (6-in × 2-in) channel strut connected the two foundation tubes at ground level for increased anchorage capacity. The posts were 1.1-m (43-in) long with cross-sectional dimensions of 140 mm × 191 mm (5-1/2 in × 7-1/2 in). A 60.3-mm- (2-3/8-in-) diameter hole was drilled through the post at ground level to facilitate breaking of the post upon impact. The post bolt hole of the end post was slotted with the dimensions of 19.1 mm × 63.5 mm (3/4 in × 2-1/2 in). Post 2 was not bolted to the W-beam rail element, but rested on a shelf angle attached to the post. The bearing plate for the cable anchor was modified with two 3.45-mm- (0.136-in-) diameter holes drilled 127 mm (5 in) apart and 38.1 mm (1-1/2 in) from the top to allow attachment of the bearing plate to the end post with galvanized nails. Photographs showing the details for posts 1 and 2 are shown in figure 64.

Posts 3 through 8 in the terminal section were 1.8-m- (6-ft-) long wooden CRT posts. The W-beam rail elements were not bolted onto posts 3 through 6. In other words, the W-beam rail elements were bolted at the end post (post 1) and then the next bolted post was post 7 for an unsupported rail length of 9.5 m (31 ft, 3 in). However, it should be noted that the rail element was supported by a shelf angle at the second post (post 2). Standard 1.6-m- (5-ft, 3-in-) long S3×5.7 steel posts with 203-mm × 610-mm × 6-mm (8-in × 24-in × 1/4-in) soil plates posts were used starting at post 9 with eight spans at 0.95 m (3 ft, 1-1/2 in) and then four spans at 1.9 m (6 ft, 3 in) for the transition area. The standard 3.8-m (12-ft, 6-in) spacing was used throughout the remaining G2 guardrail system. The height of the railing dropped 76 mm (3 in) over the 3.8-m (12 ft, 6 in) transition area from post 16 to post 18 (i.e., the height of the rail at post 18 was 762 mm (30 in) and the height of the rail at post 16 was 686 mm (27 in)). Photographs showing the details at posts 1 through 8 are shown in figure 65, and posts 9 through 20 are shown in figure 66.

11.2 TEST NUMBER 471470-20 (NCHRP REPORT 350 TEST DESIGNATION 3-35)

Test vehicle: 1985 Dodge 250 Ram Pickup	Impact speed: 101.8 km/h (63.3 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 20.8 degrees
Gross static weight: 2076 kg (4577 lb)	

The vehicle impacted the terminal at post 4 (the beginning of the length of need) or 7.62 m (25 ft) downstream from the end post. As the vehicle impacted the terminal, the

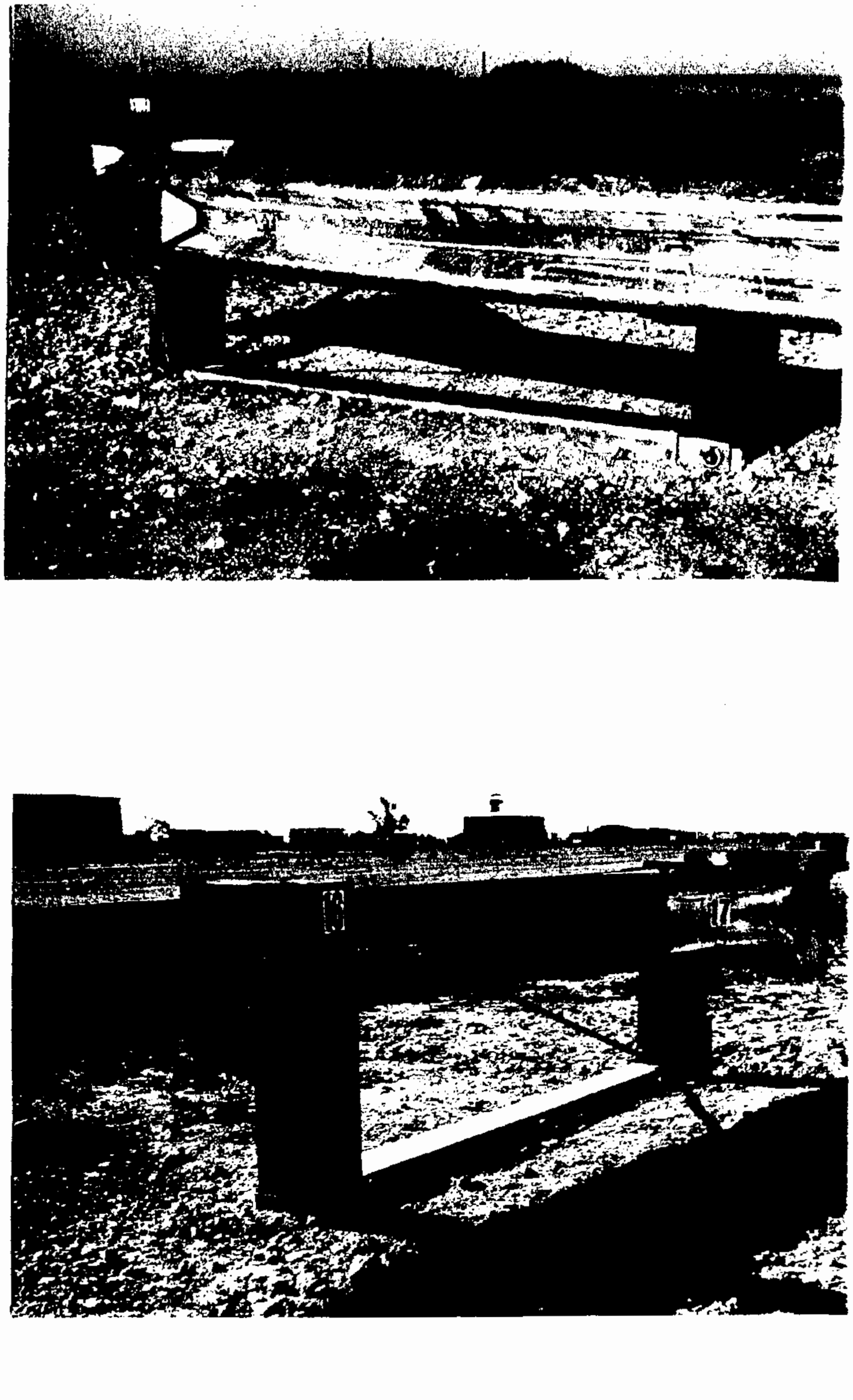
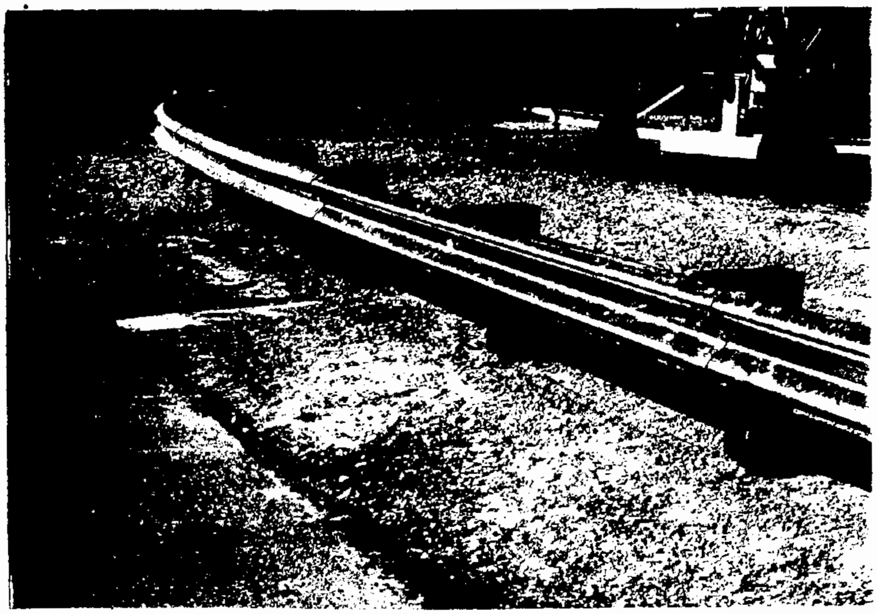


Figure 64. Modified mini-MELT posts 1 and 2 before tests 471470-24 and 25.



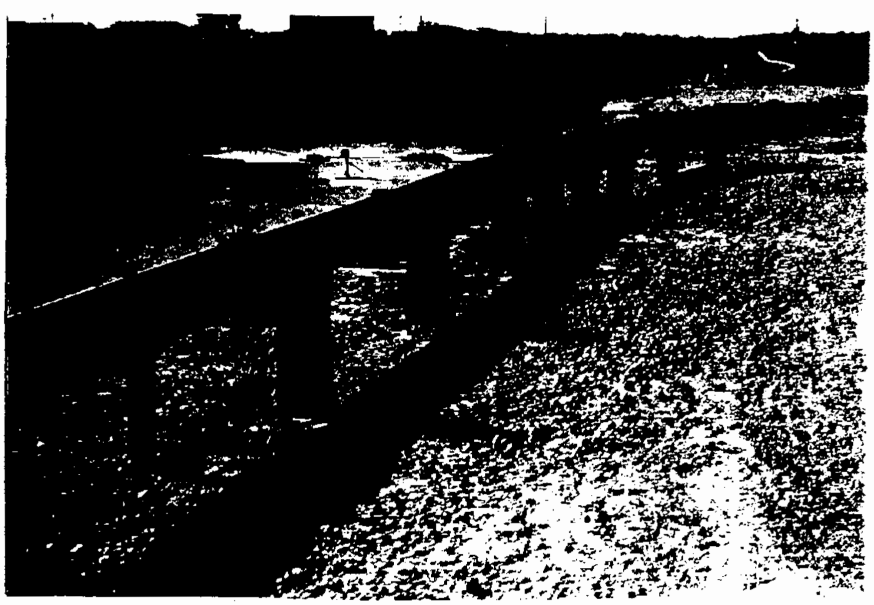


Figure 65. Posts 1 through 8 of the modified mini-MELT before tests 471470-24 and 25.

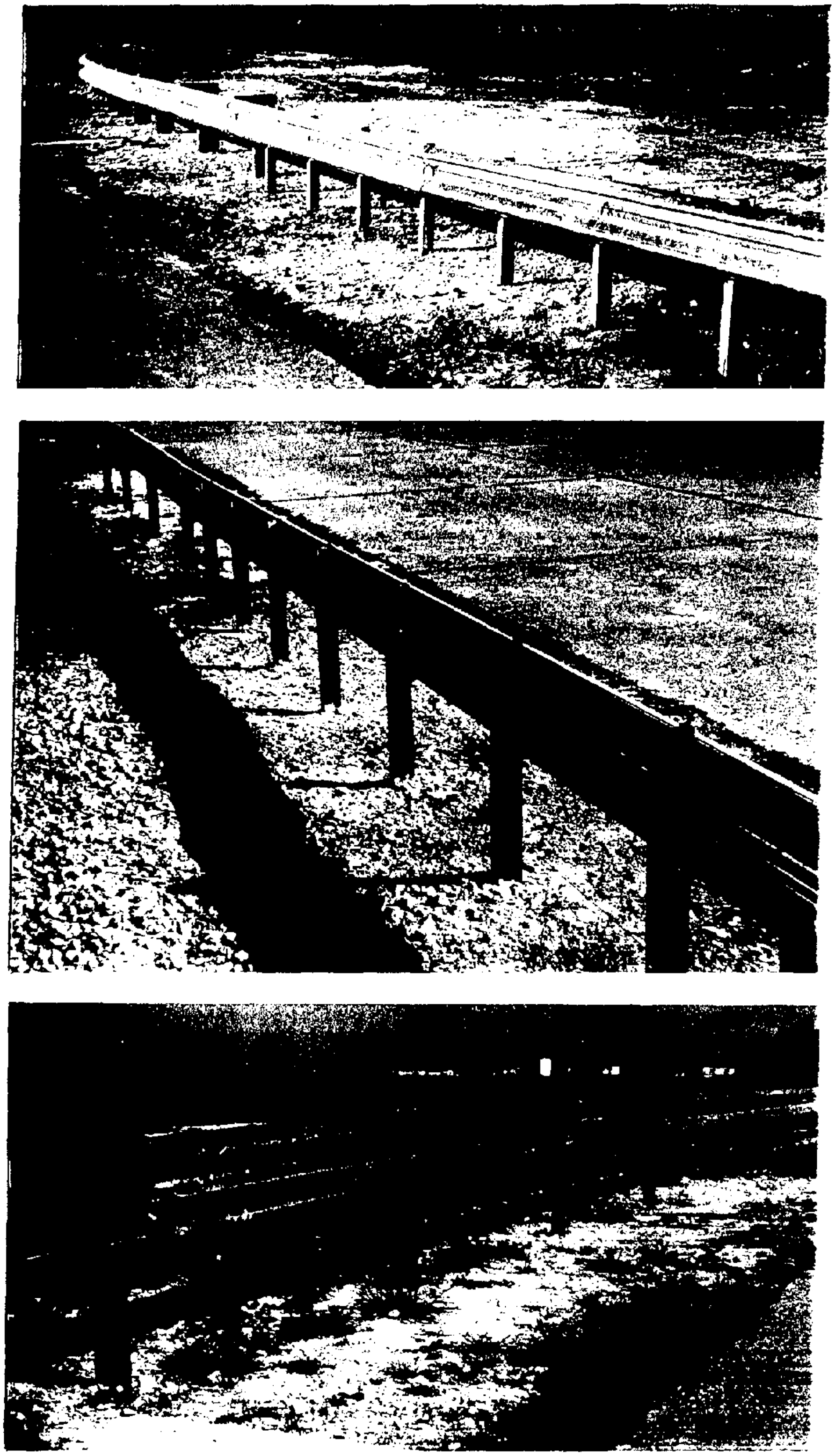


Figure 66. Posts 9 through 20 before tests 471470-24 and 25.

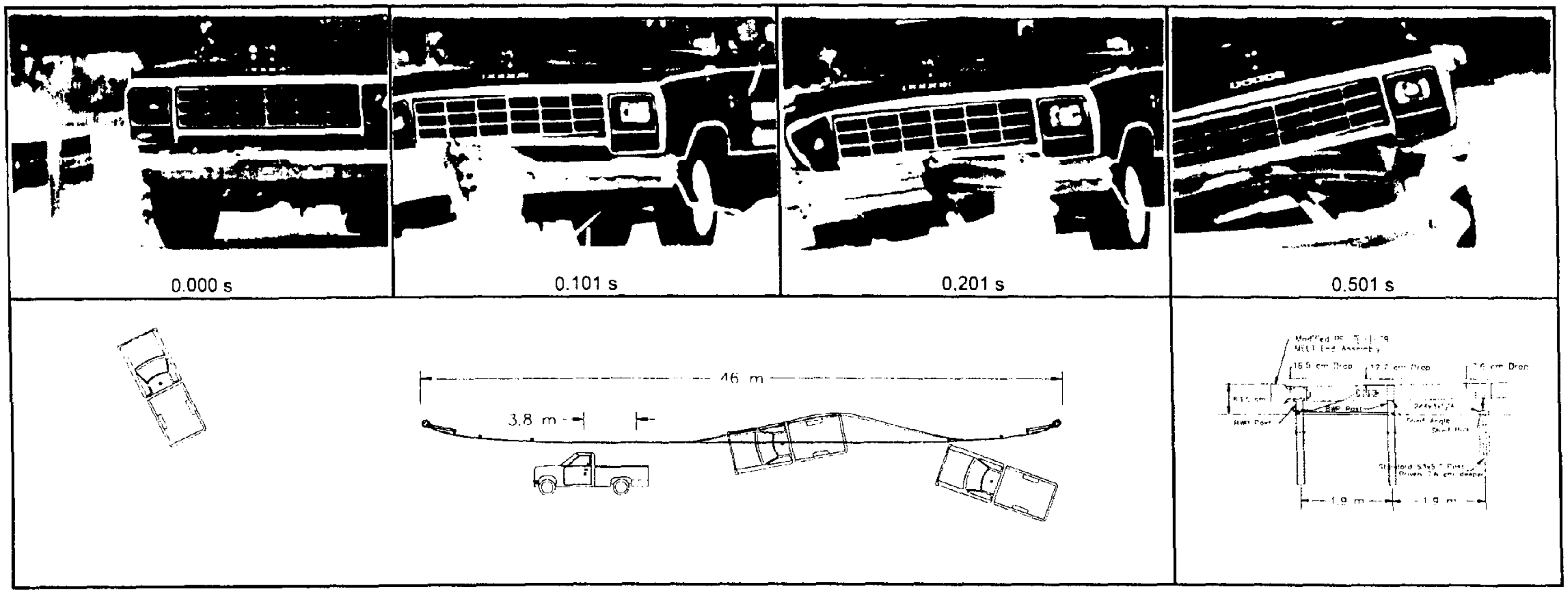
W-beam rail element began to deform, and the vehicle began to redirect. As the vehicle continued forward, the W-beam rail element rode over the top of the posts as the W-beam deformed along the path of the vehicle. The right front tire rode over post 5, causing the post to fracture just above the soil plate. The rear of the vehicle contacted the guardrail and the vehicle was traveling parallel to the installation at 78.4 km/h (48.7 mi/h). Maximum dynamic deflection of the guardrail was 2.0 m (6.7 ft). As the vehicle was being redirected, the W-beam rail element dropped and began to dig into the ground. The vehicle began to roll clockwise and the rear of the vehicle began to rise significantly. The vehicle was airborne and continued to roll clockwise as it lost contact with the installation. Shortly after that, the vehicle landed on its right side, bounced, and righted itself. The vehicle came to rest upright 90 m (296 ft) downstream and 9 m (31 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 67.

Posts 1 through 11 were displaced laterally and post 5 fractured just above the top of the soil plate. The W-beam rail element had slipped over the tops of post 4 through 8 and the maximum permanent deformation of the W-beam rail element was 1.7 m (5.5 ft). The vehicle was in contact with the installation for 25 m (81 ft). The vehicle sustained damage to the right side. The front bumper, grill, and hood were damaged and the entire right side of the body was dented and scraped. Maximum exterior crush at the right front corner at bumper height of the vehicle was 330 mm (13.0 in). There was no intrusion or deformation of the occupant compartment.

11.3 TEST NUMBER 471470-23 (NCHRP REPORT 230 TEST DESIGNATION S31)

Test vehicle: 1984 Cadillac Fleetwood	Impact speed: 97.3 km/h (60.5 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.4 degrees
Gross static weight: 2117 kg (4662 lb)	

The vehicle impacted the guardrail in the reverse direction (i.e., opposite to normal direction of travel) 4.6 m (15 ft) upstream of the last wooden post of the terminal (post 5), or 0.76 m (2 ft, 6 in) upstream of post 3. Note that the numbering system of the posts for this crash test was different from that of the other crash tests (i.e., the end post was numbered post 12, the second post numbered post 11, etc.). As the vehicle impacted the guardrail, the W-beam rail element began to deform and post 3 began to displace laterally. The front tire of the vehicle impacted post 3 and then post 4. The W-beam rail element ruptured at the splice at post 5 (last wood post of the terminal section). Just before the rupture, the rail element had deflected 0.3 m (1.09 ft), but post 5 did not deflect laterally. The vehicle impacted the end of the ruptured rail and post 5 while the vehicle was traveling at 85.3 km/h (53.0 mi/h). The W-beam rail was loaded axially, the bolt in post 6 pulled out, and subsequently the rail element buckled at the post 6 location. The axial loading and longitudinal movement of the W-beam rail element caused the end post (post 12) to fracture just above ground level. The vehicle continued forward through the opening in the rail, making contact with and fracturing



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-20
Date	09/09/93
Test Article	
Type	Terminal
Name or Manufacturer	Mini-MELT
Installation Length (m)	46 (150 ft)
Size and/or Dimension and Material of Key Elements	635-762 mm (25-30 in) mount ht W-Beam (ARTBA RE-3-73) on S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Dodge Custom 250
Mass (kg) Curb	1920 (4229 lb)
Test Inertial	2000 (4405 lb)
Dummy	78 (172 lb)
Gross Static	2078 (4577 lb)

Impact Conditions	
Speed (km/h)	101.8 (63.3mi/h)
Angle (deg)	20.8
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.1 (13.3 ft/s)
y-direction	3.0 (9.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.6
y-direction	-4.4
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-1.7
y-direction	-2.9
z-direction	1.4

Test Article Deflections (m)	
Dynamic	2.0 (6.7 ft)
Permanent	1.7 (5.5 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ4 & 01LD2
CDC	01FREK3 & 01RDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	330 (13.0 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	90
Max. Pitch Angle (deg)	4
Max. Yaw Angle (deg)	-42

Figure 67. Summary of results for test 471470-20.

posts 6 and 7 just below ground level. The vehicle lost contact with the separated terminal end section and was traveling at a speed of 70.8 km/h (44.0 mi/h). As the vehicle continued behind the installation, it began to slide sideways as it yawed counterclockwise. The vehicle came to rest 61 m (201 ft) downstream and 21 m (70 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 68.

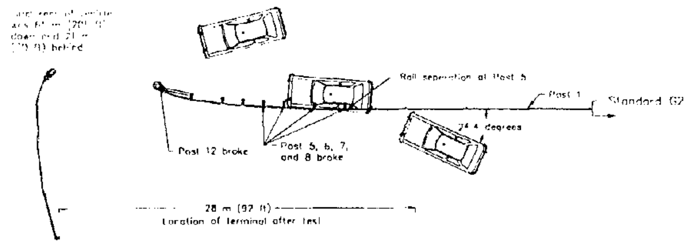
Post 1 was displaced 32 mm (2.3 in), post 2 - 127 mm (5.0 in), post 3 - 191 mm (7.5 in), and post 4 - 279 mm (11.0 in). Posts 5 through 8 were fractured below ground level and post 12 (end post) was fractured at ground level where the 60.3-mm- (2-3/8-in-) diameter hole had been drilled. Posts 9, 10, and 11 were not damaged or displaced. The W-beam rail element ruptured at the bolt holes on the underlapped element at the splice located at post 5 (last wooden post of the terminal). The maximum dynamic deflection before the rail rupture was 0.3 m (1.09 ft).

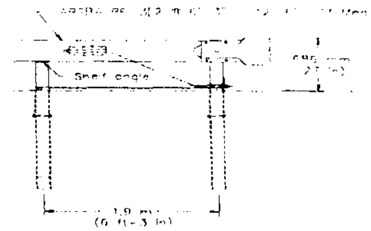
The vehicle's front stabilizer bar was bent, the windshield was cracked, and the right rear tire was aired out. The front bumper, grill, hood, fan, radiator, air conditioner compressor, and the left and right front quarter panels were also damaged. Maximum exterior crush at the right front corner of the vehicle was 300 mm (11.8 in) at bumper height. There was no intrusion or deformation of the occupant compartment.

11.4 TEST NUMBER 471470-24 (NCHRP REPORT 230 TEST DESIGNATION S31)

Test vehicle: 1982 Cadillac Coupe	Impact speed: 97.8 km/h (60.8 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.7 degrees
Gross static weight: 2118 kg (4664 lb)	

The vehicle impacted the transition area in the reverse direction (i.e., opposite to normal direction of travel) just upstream of post 13 (i.e., 4.6 m (15 ft) upstream of the last wooden post (post 8) of the Mini-MELT). As the vehicle impacted the terminal, the W-beam rail element began to deform and posts 12 and 13 began to displace laterally. The front tire of the vehicle impacted post 13 shortly afterwards, and movement began at posts 11, 14, and 10, respectively. The vehicle contacted post 12, and the right front tire aired out as it rode over post 12. Contact was made with post 11 and post 10 and the rear of the vehicle made contact with the rail near post 14. The vehicle then made contact with post 9 and post 8. The vehicle became parallel with the installation traveling at 73.2 km/h (45.5 mi/h). Maximum deflection of 0.96 m (3.15 ft) occurred near the post 10 location. The vehicle lost contact with the installation traveling at a speed of 58.4 km/h (36.3 mi/h) and at an exit angle of 8.8 degrees. As the vehicle exited the rail, it began to yaw clockwise, and subsequently came to rest 35 m (116 ft) downstream and 1.8 m (6 ft) forward of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 69.



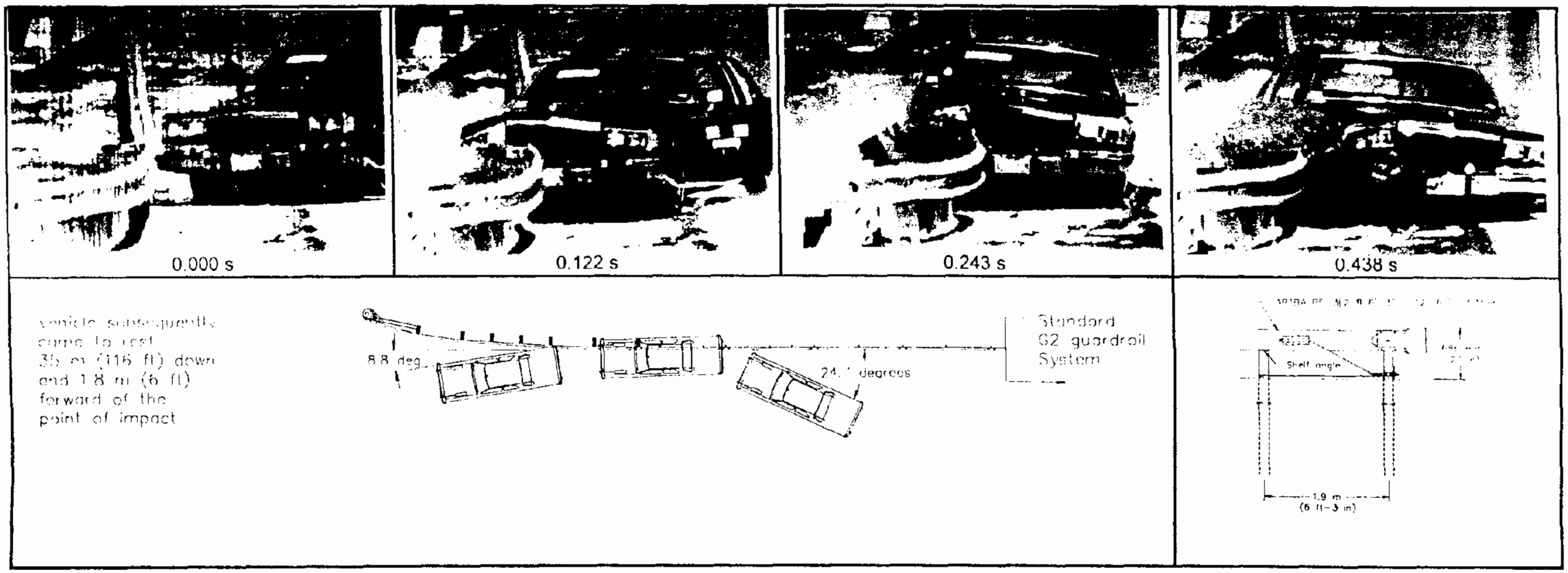


General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-23
Date	02/28/94
Test Article	
Type	Terminal
Name or Manufacturer	Modified MELT
Installation Length (m)	76 (250 ft)
Size and/or Dimension and Material of Key Elements	Modified MELT On G2 Weak-Post Guardrail System
Soil Type and Condition . . .	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2043 kg (4500 lb)
Model	1984 Cadillac Fleetwood
Mass (kg) Curb	1778 (3915 lb)
Test Inertial	2043 (4500 lb)
Dummy . . .	75 (165 lb)
Gross Static	2117 (4662 lb)

Impact Conditions	
Speed (km/h)	97.3 (60.5 mi/h)
Angle (deg)	24.4
Exit Conditions	
Speed (km/h)	70.8 (44.0 mi/h)
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.9 (19.4 ft/s)
y-direction	2.5 (8.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-8.1
y-direction	-3.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.9
y-direction	-2.7
z-direction	-3.1

Test Article Deflections (m)	
Dynamic	0.3 (1.09 ft) (Before Separation)
Permanent	Separated
Vehicle Damage	
Exterior	
VDS	12FC6
CDC	12FCEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm) . .	300 (11.8 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg) . . .	20
Max. Pitch Angle (deg) . .	3
Max. Yaw Angle (deg) . . .	-49

Figure 68. Summary of results for test 471470-23.



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-24
Date	03/22/94
Test Article	
Type	Terminal
Name or Manufacturer	Modified MELT
Installation Length (m)	76 (250 ft)
Size and/or Dimension and Material of Key Elements	Modified MELT On G2 Weak-Post Guardrail System
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2043 kg (4500 lb)
Model	1982 Cadillac Coupe
Mass (kg) Curb	1725 (3798 lb)
Test Inertial	2043 (4500 lb)
Dummy	75 (165 lb)
Gross Static	2118 (4664 lb)

Impact Conditions	
Speed (km/h)	97.8 (60.8 mi/h)
Angle (deg)	24.7
Exit Conditions	
Speed (km/h)	58.4 (36.3 mi/h)
Angle (deg)	8.8
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.3 (20.6 ft/s)
y-direction	4.8 (15.8 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-6.5
y-direction	-9.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.2
y-direction	-5.8
z-direction	2.0

Test Article Deflections (m)	
Dynamic	0.96 (3.15 ft)
Permanent	0.55 (1.80 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ3 & 01RD4
CDC	01FREK3 & 01RDEW2
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	350 (13.8 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	-11
Max. Pitch Angle (deg)	3
Max. Yaw Angle (deg)	-31

Figure 69. Summary of results for test 471470-24.

The bolts were pulled out of the W-beam rail element at posts 10 and 12. None of the posts broke off, but some posts were pushed back. The W-beam rail element sustained some local deformation at post 8 (the first wood post) and there was evidence of tire contract with post 8. Maximum dynamic deflection of the guardrail during the test was 0.96 m (3.15 ft) at post 10. Maximum permanent deformation of the guardrail was 0.55 m (1.80 ft), also at post 10. The vehicle was in contact with the guardrail system for a total length of 9.6 m (31.5 ft).

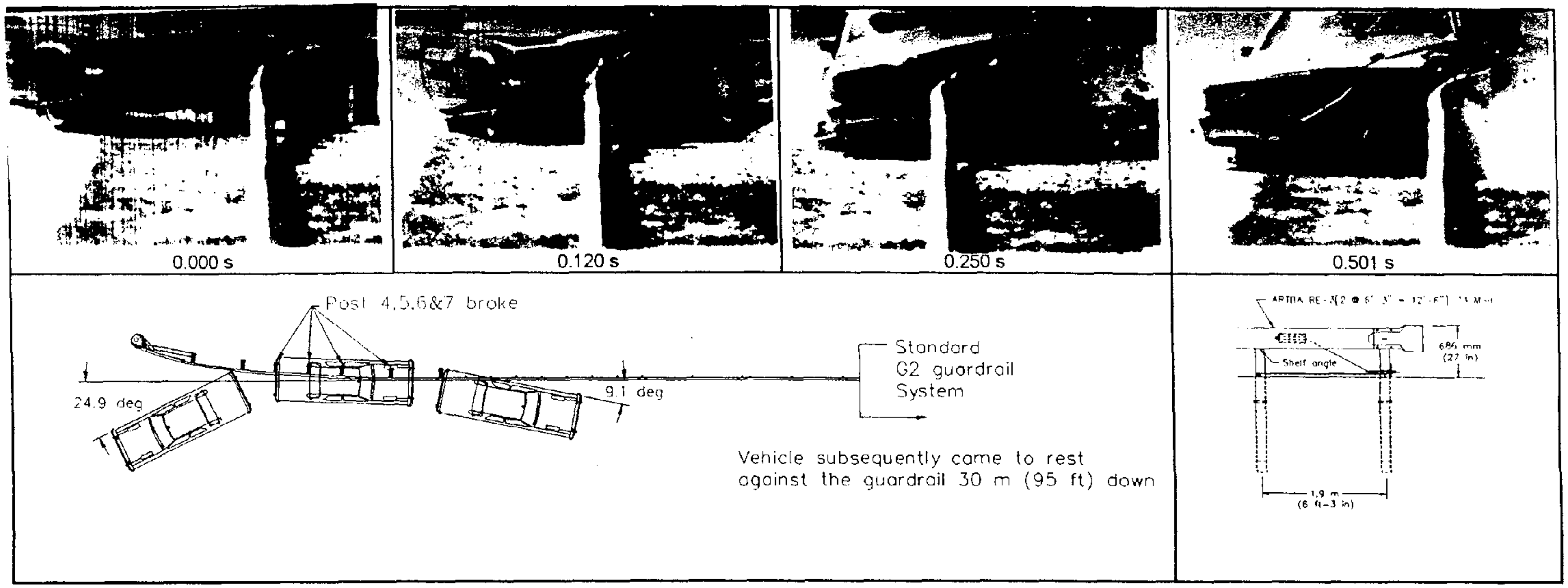
The drive shaft was bent, the lower right A-arm was damaged, and the right rear axle mount broke on the vehicle. The right front and rear tires were aired out and the rims were bent. The front bumper, grill, hood, the left and right front quarter panels, the right door, the right rear quarter panel, and the rear bumper were also damaged. Maximum exterior crush at the right front corner of the vehicle was 350 mm (13.8 in) at bumper height. There was no intrusion or deformation of the occupant compartment.

11.5 TEST NUMBER 471470-25 (NCHRP REPORT 230 TEST DESIGNATION 40)

Test vehicle: 1986 Cadillac Sedan	Impact speed: 97.8 km/h (60.8 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.9 degrees
Gross static weight: 2119 kg (4666 lb)	

The vehicle impacted the terminal just upstream of post 3 (i.e., at the beginning of length of need) or 3.8 m (12 ft, 6 in) downstream of the end post. As the vehicle impacted the terminal, the W-beam rail element began to deform and post 4 began to displace laterally. The front tire of the vehicle impacted post 3 and the W-beam element began to displace forward at post 5. The vehicle began to redirect and made contact with post 4. The W-beam began to pull back to post 5, and then to bend near post 6. Post 4 fractured at ground level, post 5 fractured and the vehicle rode over it. Post 6 fractured, the vehicle impacted the post, and the rear of the vehicle made contact with the W-beam element. The front of the vehicle contacted post 7, fracturing the post, and at the same time, the vehicle became parallel with the installation traveling at 75.3 km/h (46.8 mi/h). Maximum dynamic deflection of 1.2 m (3.8 ft) occurred between the post 6 and 7 locations. The front tire contacted post 9 and the tire aired out. The vehicle lost contact with the installation traveling at 52.3 km/h (32.5 mi/h) and at an exit angle of 9.1 degrees. As the vehicle exited the rail, it began to yaw counterclockwise, subsequently impacting the guardrail 27 m (89 ft) downstream of the point of initial impact. The vehicle rode along the guardrail for 1.9 m (6.3 ft) and stopped against the guardrail. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 70.

Posts 4 through 7 broke off near ground level, and the blockout on post 8 was splintered. A number of other posts were pushed back. For posts 4 through 7 that broke off, the post displacement measurements indicate maximum post movement just prior to breaking of the posts. The W-beam rail element was buckled and torn (but not ruptured) at the lower splice bolts on the outer edge of the splice located at post 8. The tearing propagated over half the width of the W-beam rail element, indicating that the tensile capacity of the W-beam rail



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-25
Date	03/31/94
Test Article	
Type	Terminal
Name or Manufacturer	Modified MELT
Installation Length (m)	76 (250 ft)
Size and/or Dimension and Material of Key Elements	Modified MELT On G2 Weak-Post Guardrail System
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2043 kg (4500 lb)
Model	1986 Cadillac Sedan
Mass (kg) Curb	1727 (3803 lb)
Test Inertial	2043 (4500 lb)
Dummy	75 (165 lb)
Gross Static	2119 (4666 lb)

Impact Conditions	
Speed (km/h)	97.8 (60.8 mi/h)
Angle (deg)	24.9
Exit Conditions	
Speed (km/h)	58.4 (36.3 mi/h)
Angle (deg)	9.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.0 (19.7 ft/s)
y-direction	4.6 (15.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-5.7
y-direction	-6.8
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.8
y-direction	5.6
z-direction	-2.1

Test Article Deflections (m)	
Dynamic	1.2 (3.8 ft)
Permanent	0.8 (2.5 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ5 & 11LD5
CDC	11FYEK3 & 11LDEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	380 (15.0 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	9
Max. Pitch Angle (deg)	5
Max. Yaw Angle (deg)	36

Figure 70. Summary of results for test 471470-25.

element was reached. Maximum dynamic deflection of the W-beam during the test was 1.2 m (3.8 ft) between posts 6 and 7. Maximum permanent deformation of the W-beam was 0.8 m (2.5 ft) at the post 6 location. The vehicle was in contact with the terminal for a total length of 8.9 m (29.2 ft).

The vehicle's outer tire rod and lower A-arm on the left side, and the sway bar were damaged. The right front and rear tires were aired out and the rims were bent. The front bumper, grill, hood, the left and right front quarter panels, the left door, the left rear quarter panel, and the rear bumper also were damaged. Maximum exterior crush at the left front corner of the vehicle was 380 mm (15.0 in) at bumper height. There was no intrusion or deformation of the occupant compartment.

11.6 SUMMARY OF FINDINGS

In the first crash test (test no. 471470-20) with the initial design, the mini-MELT successfully contained and redirected the vehicle. Post 5 fractured during the test sequence, but exhibited no undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. However, as the vehicle was being redirected past the point where the vehicle was parallel with the installation, the vehicle began to roll clockwise. The clockwise roll continued as the vehicle separated from the guardrail. The vehicle eventually rolled 90 degrees onto its right side and then righted itself upon contact with the pavement. The trajectory of the vehicle was judged to pose a minimal hazard to adjacent traffic as the vehicle was traveling almost parallel to the installation after separation and subsequently came to rest 9 m (31 ft) behind the point of impact. The occupant risk factors were all well within the desirable limits set forth in NCHRP 350, as shown in table 28. The impact performance of the mini-Melt was considered unsatisfactory in this test because of the rollover.

In the second crash test (test no. 471470-23) on the transition section between the G2 guardrail system and the modified mini-MELT, the guardrail failed to contain or redirect the impacting vehicle in this reverse-direction test. The W-beam rail element ruptured at the last wooden post of the terminal section (post 5), allowing the vehicle to penetrate and travel behind the test installation. The end post was fractured and the separated end terminal section was thrown forward during the test sequence, which could potentially pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during the initial collision period. The trajectory of the vehicle was judged to have posed a minimal hazard to adjacent traffic as the vehicle penetrated and came to rest behind the guardrail. Although not required as part of the evaluation criteria for this test, the occupant risk factors were all well within the desirable limits set forth in NCHRP Report 230. In summary, the transition section between the Mini-MELT and the standard G2 guardrail system failed to contain and redirect the test vehicle and was judged to have failed the evaluation criteria set forth in NCHRP Report 230, as summarized in table 29.

Table 28. Assessment of results of test 471470-20 (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute | Test No.: 471470-20 | Test Date: 09/09/93

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Mini-MELT contained and redirected the vehicle. A maximum dynamic deflection of 2.0 m (6.7 ft) was attained with a residual deformation of 1.7 m (5.5 ft).	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Post 5 fractured at ground level as the vehicle's front wheel rode over it; however, it remained where it separated and did not exhibit any hazard to occupants, adjacent traffic, or others in the area. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle rolled 90 degrees onto its right side as the vehicle was being redirected. The vehicle then righted itself upon contact with the pavement.	Fail
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory does not intrude into adjacent traffic lanes.	Vehicle intrusion into adjacent traffic lanes was judged as minimal.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.1 m/s Longitudinal Ridedown Acceleration = -3.6 g's	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle was out of view from the overhead camera and airborne as it lost contact with the installation; however, it was traveling almost parallel with the installation.	Pass

Table 29. Assessment of results of test 471470-23 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute — Test No.: 471470-23 — Test Date: 02/28/94

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 transition section between the Mini-MELT and the G2 guardrail system failed to contain or redirect the impacting vehicle. The W-beam rail element was ruptured at a splice, allowing the vehicle to penetrate and travel behind the test installation.	Fail
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 hazards to other traffic.	A section of the Mini-MELT was detached from the test installation and was thrown forward, thereby presenting potential hazards to adjacent traffic.	Fail
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.	The vehicle remained upright and relatively stable during the initial collision period. There was no penetration or intrusion into the passenger compartment.	Pass
Vehicle Trajectory H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Not applicable. The vehicle penetrated the installation and came to rest behind the test installation.	N/A
I. In a test 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 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.	Not applicable. The vehicle penetrated the installation and came to rest behind the test installation.	N/A

The third crash test (test no. 471470-24) was a repeat of the second crash test on a redesigned mini-MELT. The vehicle was successfully contained and smoothly redirected in this test. The maximum dynamic deflection of the guardrail was 0.96 m (3.15 ft). There were no detached elements or debris to exhibit undue hazards to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed a minimal hazard to adjacent traffic as the vehicle came to rest 1.8 m (6 ft) forward of the installation. Although not required as part of the evaluation criteria for this test, the occupant risk factors were well within the desirable limits set forth in NCHRP Report 230. The modified Mini-MELT was judged to have performed satisfactorily in this transition test.

The modified mini-MELT was then evaluated on the adequacy or strength of the anchorage in the fourth crash test (test no. 471470-25). The terminal successfully contained and smoothly redirected the impacting vehicle. The maximum dynamic deflection of the guardrail was 1.2 m (3.8 ft). The W-beam rail element was buckled and partially torn (but not ruptured) at the lower splice bolts on the outer edge of the splice located at the last wooden post (post 8). Some posts broke off and came to rest behind the test installation, but did not exhibit undue hazards to adjacent traffic or show potential for penetration of the occupant compartment. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed no potential hazard to adjacent traffic as the vehicle came to rest against the installation. Although not required as part of the evaluation criteria for this test, the occupant risk factors were well within the desirable limits set forth in NCHRP Report 230. The modified mini-MELT was judged to have performed satisfactorily in this length-of-need strength test.

In summary, the impact performance of the modified mini-MELT in the third and fourth crash tests was considered acceptable according to guidelines set forth in NCHRP Report 230, as shown in tables 30 and 31. However, it appeared that the system was performing at or near its performance limit as evidenced by the partial tearing (more than 50 percent) of the W-beam rail element in the length-of-need strength test. The W-beam rail element could easily have been torn completely and allowed the vehicle to penetrate the barrier had the impact conditions been slightly more severe.

Table 30. Assessment of results of test 471470-24 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-24 | Test Date: 03/22/94

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 modified Mini-MELT contained and redirected the impacting vehicle. The vehicle did not penetrate or go over the installation.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present an undue hazard to other traffic.	There were no detached elements or other debris to present a hazard to occupants or 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.	The vehicle remained upright and relatively stable during the initial collision period. There was no penetration or intrusion into the passenger compartment.	Pass
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 intrusion into adjacent traffic lanes was judged as minimal as the vehicle came to rest 1.8 m (6 ft) forward of the installation.	Pass
I. In a test 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 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 a test device.	The change in speed of the vehicle at loss of contact was 12.2 km/h (7.6 mi/h). The exit angle was less than 60 percent of the impact angle.	Pass

Table 31. Assessment of results of test 471470-25 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-25 | Test Date: 03/31/94

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 modified Mini-MELT contained and redirected the impacting vehicle. The vehicle did not penetrate or go over the installation. There was, however, some buckling and partial tearing of the W-beam rail element at the lower splice on post 5.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present an undue hazard to other traffic.	There was no penetration of the occupant compartment. Some posts broke off and were thrown behind the installation, exhibiting no potential hazard to adjacent 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.	The vehicle remained upright and relatively stable during the initial collision period. There was no penetration or intrusion into the passenger compartment.	Pass
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	The vehicle came to rest against the installation and did not intrude into adjacent traffic lanes.	Pass
I. In a test 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 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 a test device.	Not applicable.	N/A

XII. EXISTING GUARDRAIL SYSTEMS

The FHWA has formally adopted the new performance evaluation guidelines for highway features set forth in NCHRP Report 350 as a "Guide or Reference" document in *Federal Register*, Volume 58, Number 135, dated July 16, 1993, which added paragraph (a)(13) to 23 CFR, Part 625.5. FHWA has also mandated that, starting in September of 1998, only highway safety appurtenances that have successfully met the performance evaluation guidelines set forth in NCHRP Report 350 may be used on the National Highway System (NHS) for new installations. Most of the existing highway features were tested according to the previous guidelines contained in NCHRP Report 230. It is, therefore, necessary to crash test and evaluate the performance of existing highway features under the newer guidelines.

One of the key revisions in the guidelines set forth in NCHRP Report 350 from those in NCHRP Report 230 is the replacement of the 2041-kg (4500-lb) passenger car by a 2000-kg (4409-lb) pickup truck as one of the design test vehicles. Very little information was available on the performance of existing highway features with the new 2000P test vehicle (i.e., 2000-kg (4409-lb) pickup truck). As part of an effort by FHWA to evaluate the performance of existing highway features with the new 2000P test vehicle, a series of crash tests with the new 2000P test vehicle were conducted on various existing guardrail systems, including:

- Cable (G1) guardrail system,
- W-beam, weak-post (G2) guardrail system,
- Box-beam (G3) guardrail system,
- W-beam, strong-post (G4) guardrail system,
- Thrie-beam (G9) guardrail system, and
- Modified thrie-beam guardrail system.

This chapter presents the results of crash tests on these existing guardrail systems. Testing and evaluation was performed according to guidelines outlined in NCHRP Report 350.

12.1 TEST INSTALLATIONS

12.1.1 Cable (G1) Guardrail System

The cable (G1) guardrail system consisted of three 191-mm- (3/4-in-) diameter round wire cable mounted on S3x5.7 steel posts, spaced 4.9 m (16 ft) on center, a cross-section of which is shown in figure 71. The 19.1-mm- (3/4-in-) diameter round wire cable consisted of three strands (seven wires per strand) with a minimum tensile strength of 115.7 kN (26,000 lb). The mounting heights for the center of the three cables were 597, 673, and 749 mm (23.5, 26.5, and 29.5 in), respectively. The cables were attached to the posts with 7.9-mm (5/16-in) diameter hook bolts. The S3x5.7 steel posts were 1.6 m (63 in) long with

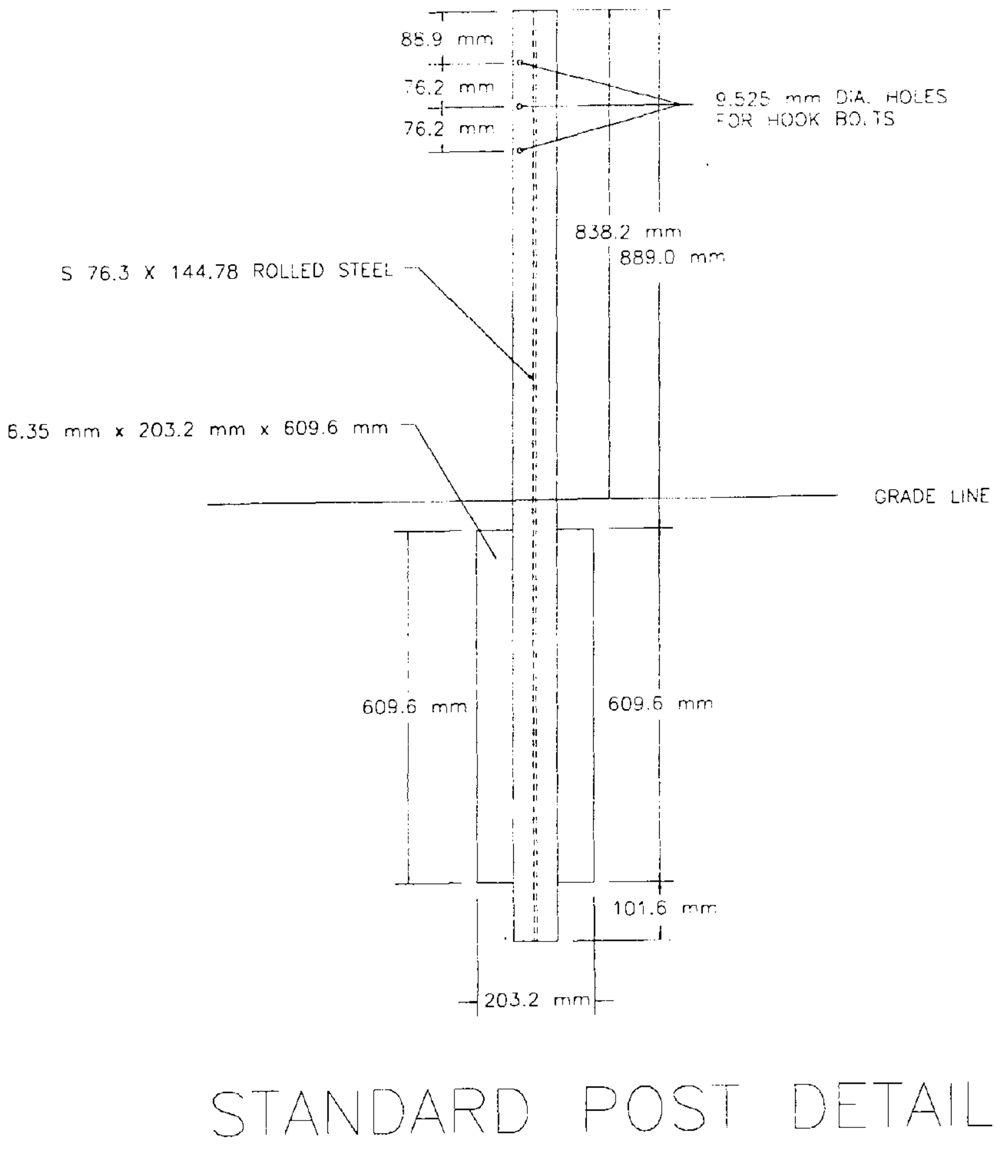


Figure 71. Cross-section of the cable (G1) guardrail system.

an embedment depth of 762 mm (30 in). A 203-mm × 610-mm × 6.4-mm (8-in × 24-in × 1/4-in) soil plate was used with the steel posts.

The 12.8-m- (42-ft-) long terminal section consisted of a 7.3-m- (24-ft) section with four S3x5.7 posts spaced at 1.83 m (6.0 ft) and the last 5.5 m (18 ft) was unsupported (i.e., the first or end post was located 5.5 m (18 ft) from the concrete anchor). The full guardrail height of 762 mm (30 in) was maintained until the second post where the cables began to slope down to ground level at the concrete anchor. The first two posts had end caps with shelf angles for the cables instead of the hook bolts. The first or end post was also mounted at a reduced height to accommodate the sloping of the cables. The cables were anchored to a concrete block with a breakaway anchor angle, details of which are shown in figure 72.

12.1.2 W-Beam, Weak-Post (G2) Guardrail System

The W-beam, weak-post (G2) guardrail system consisted of 1.6-m- (5-ft, 3-in-) long S3x5.7 posts with 203-mm × 610-mm × 6.4-mm (8-in × 24-in × 1/4-in) soil plates, spaced 3.8 m (12 ft, 6 in) center to center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. A cross-section of the W-beam, weak-post (G2) guardrail system is shown in figure 73. The height of the guardrail to the top of the W-beam rail element was 0.76 m (30 in). The W-beam rail elements were attached to the posts with 7.94-mm- (5/16-in-) diameter bolts and square plate washers. Also, 12.7-mm- (1/2-in-) diameter and 38.1-mm- (1-1/2-in-) long shelf bolts were attached to the posts with two or more nuts for the W-beam rail elements to rest on. The purpose of the shelf bolts is to reduce the loading on the 7.94-mm- (5/16-in-) diameter post bolts from the weight of the W-beam rail elements and other dead load, such as snow and ice on the rail elements.

12.1.3 Box-Beam (G3) Guardrail System

The box-beam (G3) guardrail system consisted of 1.6-m- (5-ft, 4-in-) long S3x5.7 steel posts spaced 1.8 m (6 ft) apart, a cross-section of which is shown in figure 74. A L127 mm × 89 mm × 10 mm × 114 mm long (L5 in × 3-1/2 in × 3/8 in × 4-1/2 in long) shelf angle was attached to the post with a 13-mm- (1/2-in-) diameter, 38-mm- (1-1/2-in-) long hex bolt with washer and nut. A TS 152-mm × 152-mm × 4.8-mm tubular steel (TS 6-n × 6-in × 3/16-in) box-beam rail element was attached to the support angle with a 10-mm- (3/8-in-) diameter, 191-mm- (7-1/2-in-) long hex bolt with washer and nut. The mounting height of the box beam rail was 686 mm (27 in) to the top of the box-beam rail element.

12.1.4 W-beam, Strong-Post (G4) Guardrail Systems

Both W-beam, strong-post guardrail systems, one with wooden posts and blockouts, G4(2W), and the other with steel posts and blockouts, G4(1S), were crash tested.

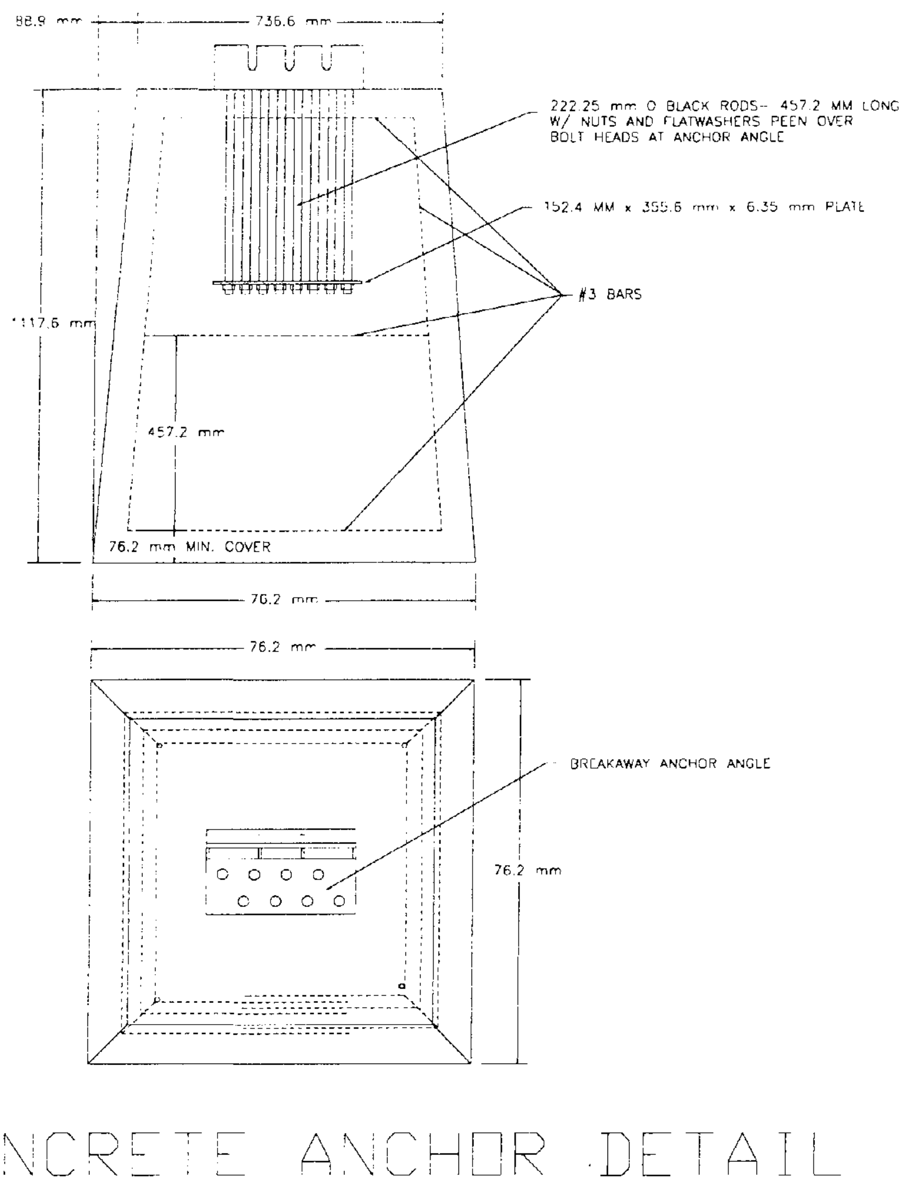


Figure 72. Details of breakaway anchor for cable (G1) guardrail system.

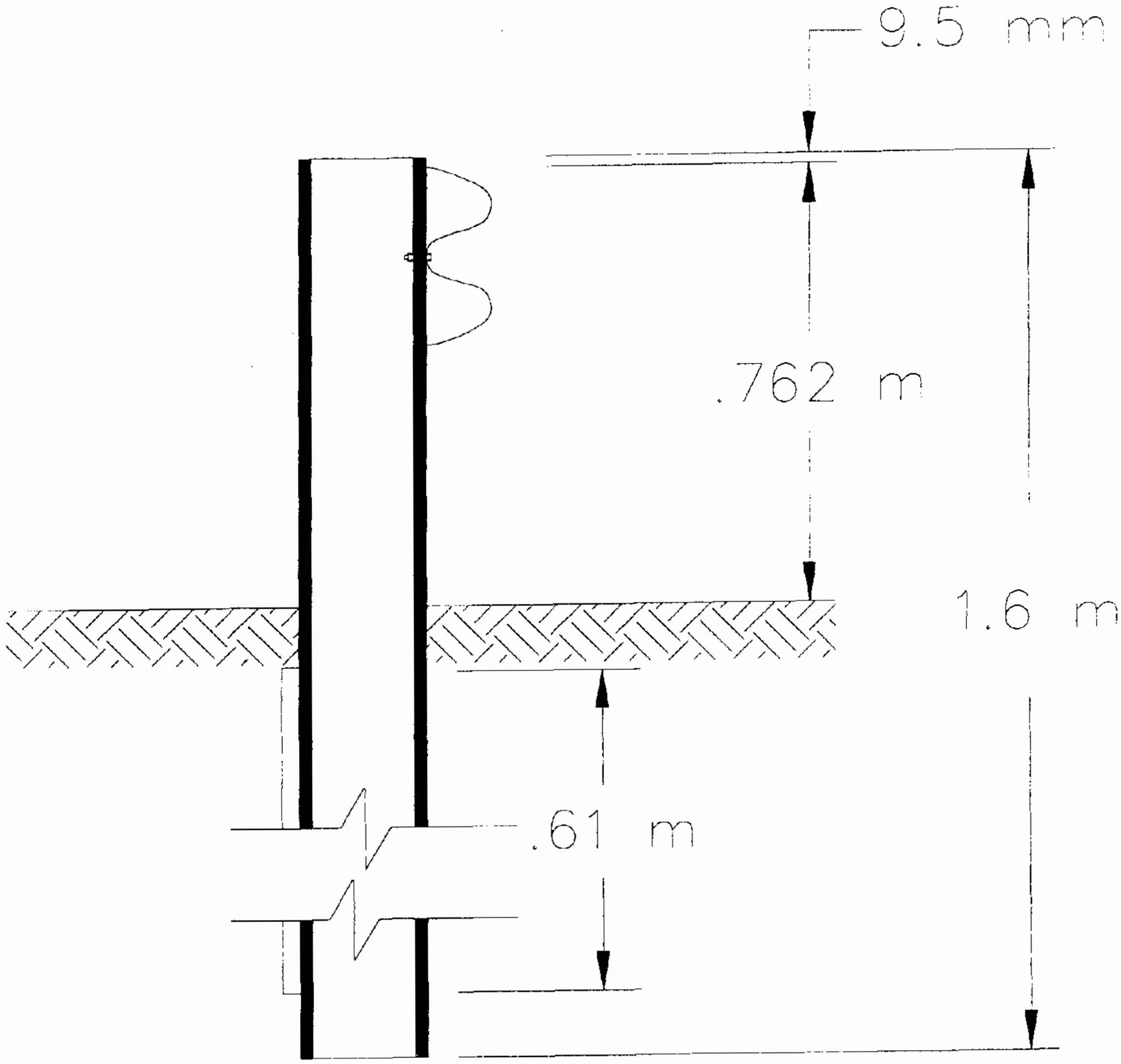


Figure 73. Cross-section of W-beam, weak-post (G2) guardrail system.

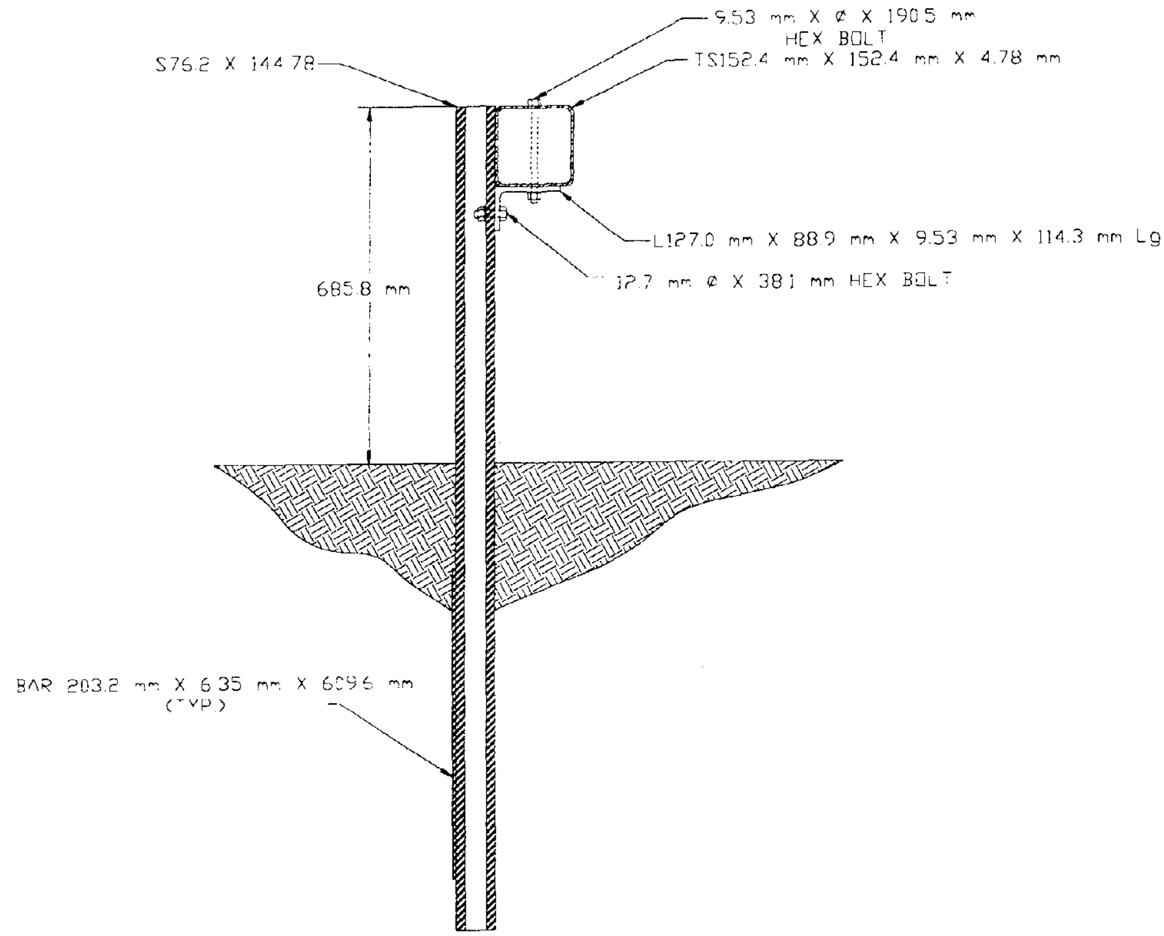


Figure 74. Cross-section of the box-beam (G3) guardrail system.

As shown in figure 75, the G4(2W) guardrail system consisted of 1.6-m- (5-ft, 4-in-) long, 152-mm × 203-mm (6-in × 8-in) wood posts with 356-mm- (14-in-) long, 152-mm × 203-mm (6-in × 8-in) wooden blockouts, spaced 1.9 m (6 ft, 3 in) on center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers.

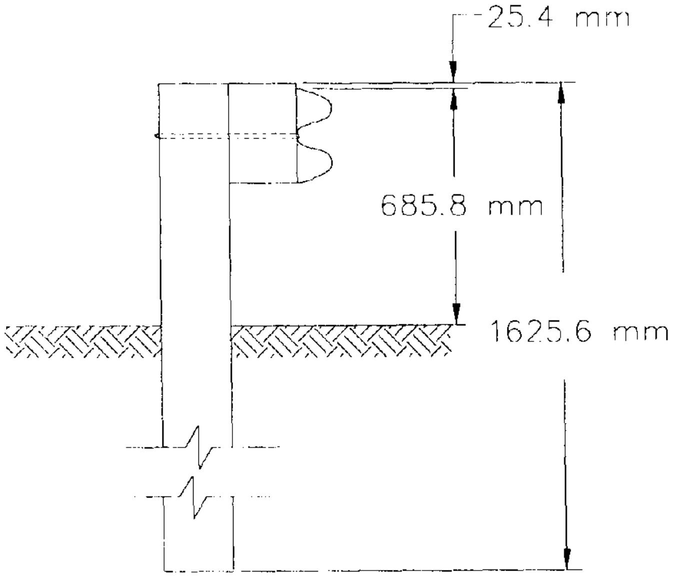
The G4(1S) guardrail system consisted of 1.8-m- (6-ft, 0-in-) long, W6x9 steel posts with 356-mm- (14-in-) long W6x9 steel blockouts, spaced 1.9 m (6 ft, 3 in) on center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. A cross-section of the G4(1S) guardrail system is shown in figure 76. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers. Backup plates, similar in cross section to the W-beam rail element and 305 mm (12 in) in length, were used at non-splice posts.

12.1.5 Thrie-Beam (G9) Guardrail System

As shown in figure 77, the thrie-beam (G9) guardrail system consisted of 2.0-m (6-ft, 6-in-) long W6x9 steel posts spaced 1.9 m (6 ft, 3 in) apart with 546-mm- (21.5-in-) long W6x9 steel blockouts. The blockout was attached to the post with two 15.9-mm- (5/8-in-) diameter bolts and the thrie-beam rail element was attached to the blockout with two 15.9-mm- (5/8-in-) diameter button head bolts without washers. The mounting height of the thrie-beam rail was 559 mm (22 in) to the center and 813 mm (32 in) to the top of the thrie-beam rail element.

12.1.6 Modified Thrie-Beam Guardrail System

The modified thrie-beam guardrail system consisted of 2.1-m- (6-ft, 9-1/4-in) long W6x9 steel posts spaced 1.9 m (6 ft, 3 in) apart with M14x18 blockouts. A cross-section of the modified thrie-beam guardrail system is shown in figure 78. The blockouts were 432 mm (17 in) long, 457 mm (18 in) deep, and 152 mm (6 in) wide at the flanges. The webbing of the blockout had a cutout measuring 152 mm (6 in) at the bottom and angled upward at 40 degrees to the flange upon which the thrie-beam was attached. The blockout was attached to the post with four 15.9-mm- (5/8-in-) diameter bolts and the thrie-beam rail element was attached to the blockout with a single 15.9-mm- (5/8-in-) diameter button head bolt without a washer. The mounting height of the thrie-beam rail was 610 mm (24 in) to the center and 864 mm (34 in) to the top of the thrie-beam rail element.



G4(2W)

Post Type:	152x203 Wood
Post Spacing:	1.9 m
Beam Type:	12-gauge W-beam
Blockout:	152x203x356 Wood
Mountings:	16 mm dia. carriage bolts

Figure 75. Cross-Section of the W-beam, wood-post (G4(2W)) guardrail system.

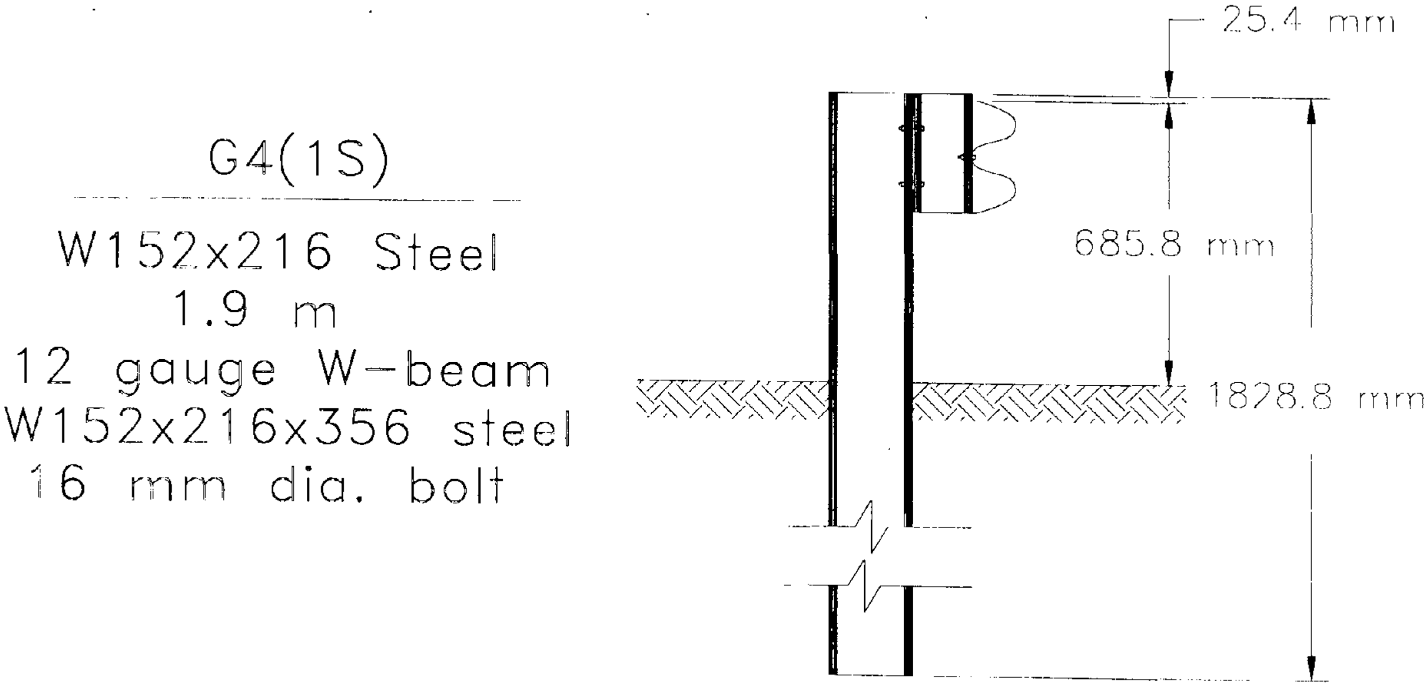


Figure 76. Cross-section of the W-beam, steel-post (G4(1S)) guardrail system.

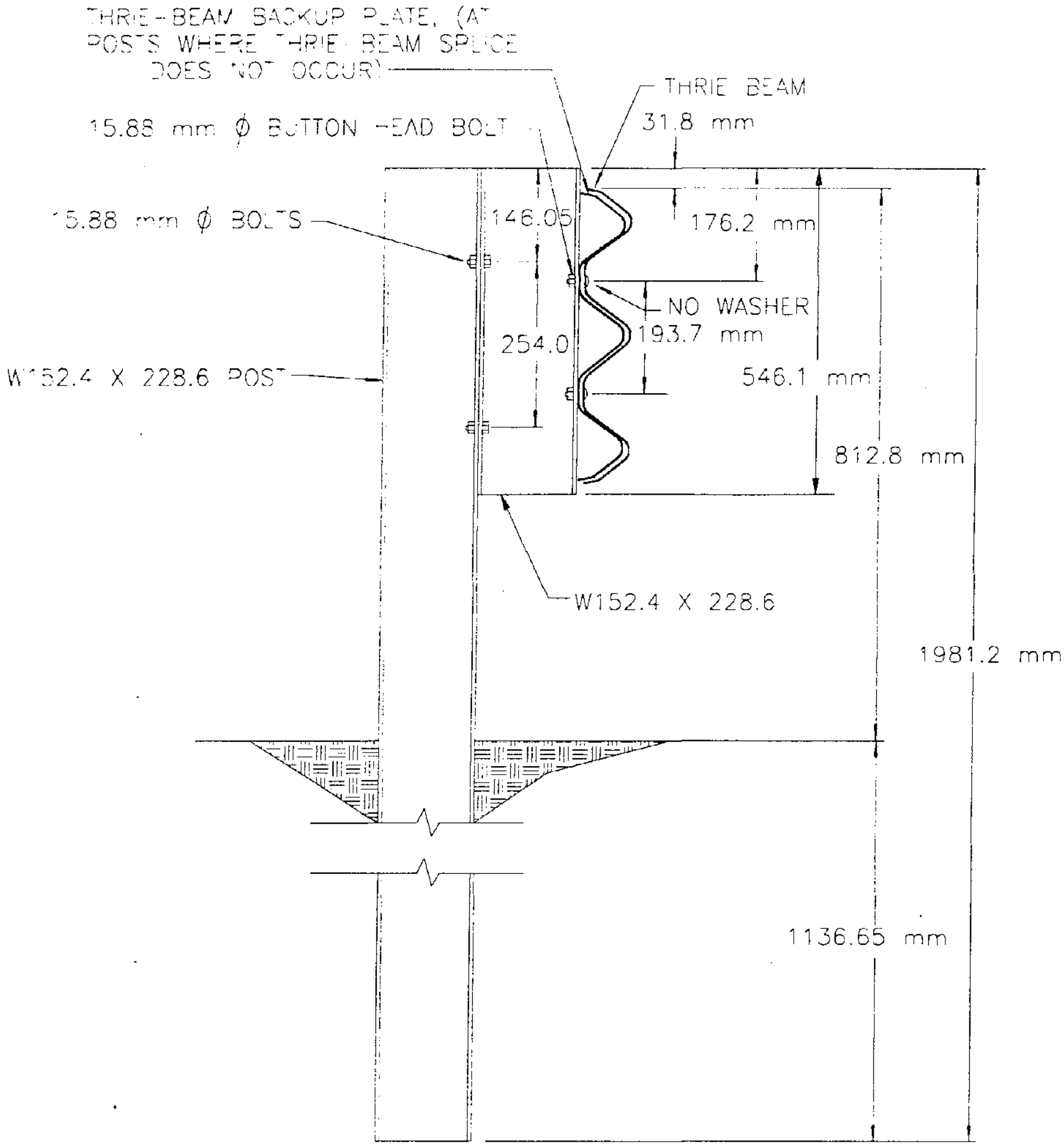


Figure 77. Cross-section of the thrie-beam (G9) guardrail system.

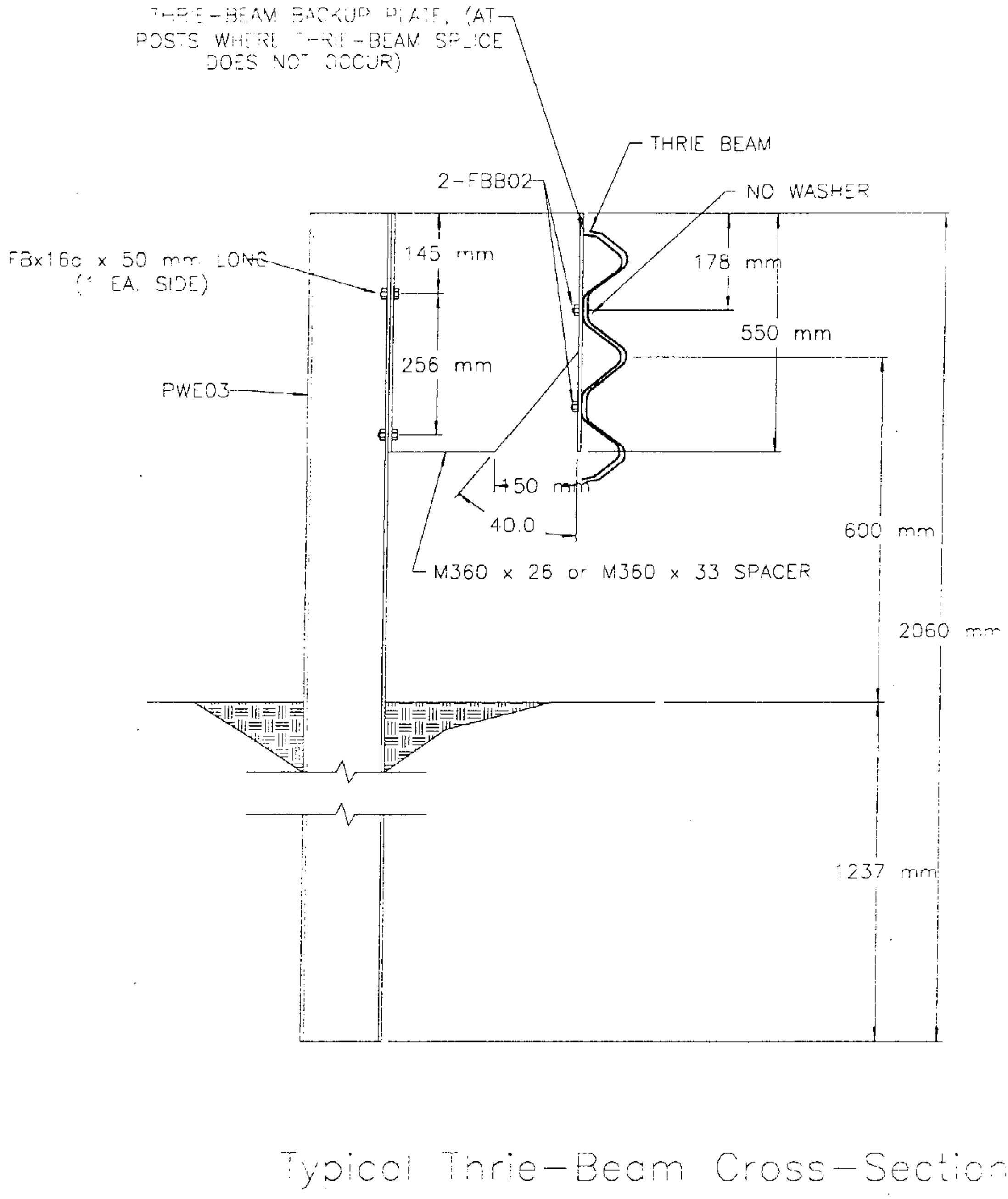


Figure 78. Cross-section of the modified thrie-beam guardrail system.

12.2 CABLE (G1) GUARDRAIL SYSTEM
Test Number 471470-28 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 Chevrolet 2500 Pickup	Impact speed: 95.1 km/h (59.1 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 26.7 degrees
Gross static weight: 2075 kg (4570 lb)	

The test installation consisted of a 92.7-m- (304-ft-) long section of the cable (G1) guardrail system with a 12.8-m- (42-ft-) long terminal at each end, for a total installation length of 118.3 m (388 ft). The vehicle impacted the length-of-need section midway between posts 10 and 11. As the vehicle impacted the installation, the cables began to deflect and the posts on either side of the impact point began to move inward and back. Redirection of the vehicle began and vehicle contact with post 11 occurred. Post 12 began to move rearward and began to pull out of the ground. The front of the vehicle contacted post 12 and the cables made contact with the entire side of the vehicle. Post 13 began to pull out of the ground. The vehicle became parallel with the installation traveling at 77.3 km/h (48.0 mi/h). Maximum deflection of the cables was 2.4 m (7.8 ft). The vehicle contacted posts 13 and 14 and then lost contact with the installation traveling at 60.3 km/h (37.5 mi/h) and at an exit angle of approximately 2.0 degrees. The vehicle brakes were applied after the vehicle exited the test area, and it subsequently came to rest 97 m (318 ft) down and 7 m (24 ft) forward of the impact point. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 79.

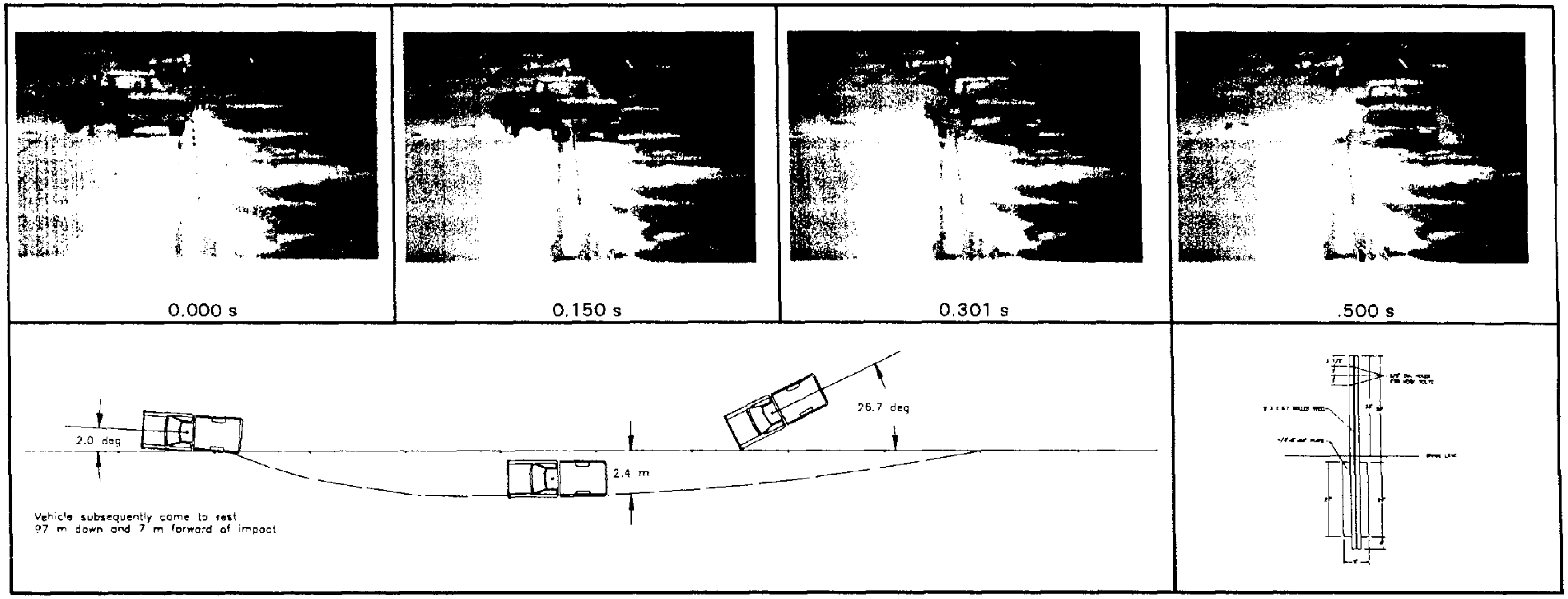
The cables were separated from the posts between posts 10 through 16. Posts 8 through 16 were pushed back or pulled out of the ground. Maximum dynamic deflection of the cables during the test was 2.4 m (7.8 ft). Maximum permanent deformation of the installation was 0.3 m (0.9 ft). The upstream concrete anchor was pulled up 89 mm (3.5 in) and inward 95 mm (3.8 in). The downstream anchor was pulled up and inward 57 mm (2.3 in).

The front bumper and grill were damaged, and the entire left side of the vehicle was scraped by the wire rope. Maximum exterior crush at the left front corner of the vehicle was 360 mm (14.2 in) and there was no deformation or intrusion into the occupant compartment.

12.3 W-BEAM, WEAK-POST (G2) GUARDRAIL SYSTEM
Test Number 471470-21 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1985 Chevrolet Pickup	Impact speed: 99.8 km/h (62.0 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 24.4 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of 45.7 m (150 ft) of length-of-need section with a 7.62-m- (25-ft-) long turned-down terminal at each of the two ends, for a total installation length of 61.0 m (200 ft). The vehicle impacted the terminal system at midspan between



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-28
Date	11/15/94
Test Article	
Type	Guardrail
Name or Manufacturer	G1 Wire Rope
Installation Length (m)	122 m (400 ft)
Size and/or Dimension and Material of Key Elements	3/4-in Round Wire Cable on S3x5.7 Steel Posts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1774 (3907 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2075 (4570 lb)

Impact Conditions	
Speed (km/h)	95.1 (59.1 mi/h)
Angle (deg)	26.7
Exit Conditions	
Speed (km/h)	60.3 (37.5 mi/h)
Angle (deg)	2.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.3 (14.2 ft/s)
y-direction	3.5 (11.6 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.0
y-direction	5.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-2.0
y-direction	2.9
z-direction	1.9

Test Article Deflections (m)	
Dynamic	2.4 (7.8 ft)
Permanent	0.3 (0.9 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ3
CDC	11FYEK1 & 11LDEW2
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	360 (14.2 in)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	10
Max. Pitch Angle (deg)	-3
Max. Yaw Angle (deg)	27

Figure 79. Summary of results for test 417470-28.

posts 5 and 6. As the vehicle impacted the guardrail installation, the W-beam rail element began to deform and post 6 and 5 began to deflect. Post 7 (second post downstream from impact) began to deflect and the vehicle began to redirect. As the vehicle continued forward, the W-beam rail element rode over the top of the posts as the W-beam deformed along the path of the vehicle. The rear of the vehicle contacted the guardrail while the vehicle was traveling parallel to the installation at 80.2 km/h (49.9 mi/h). Maximum dynamic deflection of the guardrail was 2.4 m (7.9 ft). As the vehicle was being redirected, the W-beam rail element dropped and began to dig into the ground. The left front tire began to mount the guardrail and was on top of the rail. The right front wheel came into contact with the guardrail and the left rear tire came into contact with and eventually mounted the rail. The right front wheel was on top of the rail and aired out. The W-beam rail element separated from the last post, the right front tire contacted the ground, and the vehicle separated from the guardrail. The vehicle remained upright and came to rest 28.8 m (94.6 ft) downstream and 2.4 m (8.0 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 80.

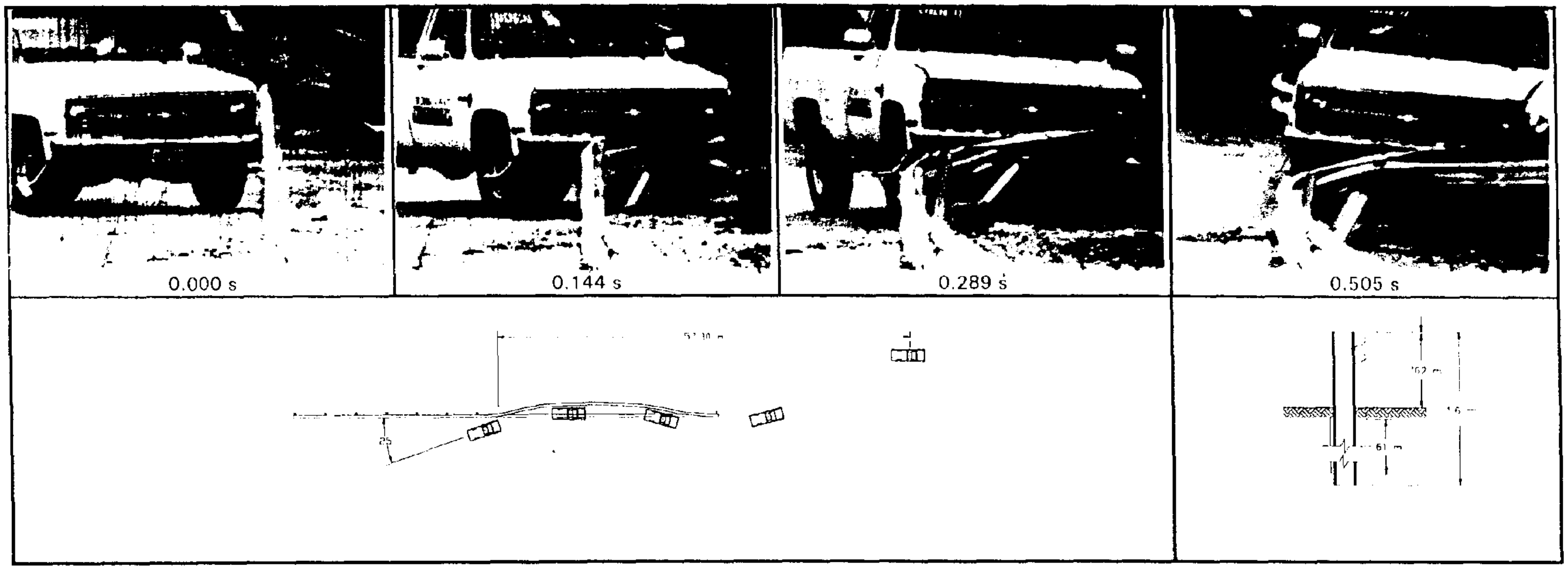
There was evidence of movement on all of the posts and the W-beam slipped over the tops of posts 5 through 13. The maximum permanent deformation of the W-beam was 1.8 m (5.9 ft). The vehicle was in contact with the installation from impact to the end of the guardrail. The left front, left rear, and right front tires of the vehicle overrode the guardrail and exited only when the end of the guardrail installation was reached. It is evident from reviewing the high-speed film that, had there been a longer run of guardrail, the vehicle would likely have vaulted over the guardrail completely, which is not acceptable.

Maximum exterior crush at the left front corner at bumper height of the vehicle was 259 mm (10.2 in), and there was no intrusion into or deformation of the occupant compartment. Damage was sustained to the front bumper, grill, hood, and along the entire left side the body panels were dented and scraped. There was slight damage to the right front corner where the vehicle came to rest against the next installation downstream.

12.4 W-BEAM, WEAK-POST (G2) GUARDRAIL SYSTEM
Test Number 471470-22 (NCHRP Report 350 test designation 2-11)

Test vehicle: 1985 Chevrolet Pickup	Impact speed: 71.0 km/h (44.1 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 26.1 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of 61.0 m (200 ft) of length-of-need section with a 7.62-m (25-ft) turned-down terminal at each of the two ends, for a total test installation length of 76.2 m (250 ft). The vehicle impacted the guardrail system at midspan between posts 4 and 5. As the vehicle impacted the guardrail installation, the W-beam rail element began to deform. Post 5 (first post downstream from impact), post 4 (first post upstream from impact), and post 6 (second post downstream from impact) began to deflect. The left front tire of the vehicle contacted post 5, resulting in the front tires being turned toward the guardrail. The vehicle began to redirect, the W-beam rail element went over the top of post 6, and then the



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-21
Date	11/17/93
Test Article	
Type	Guardrail w/Turned-Down
Name or Manufacturer	Weak-Post W-Beam (G2)
Installation Length (m)	61 (200 ft)
Size and/or Dimension and Material of Key Elements	76 cm (30 in) mount height W-Beam (ARTBA RE-3-73) S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Chevrolet Custom 20
Mass (kg) Curb	2000 (4405 lb)
Test Inertial	2000 (4405 lb)
Dummy	76 (167 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	99.8 (62.0 mi/h)
Angle (deg)	24.4
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.0 (16.4 ft/s)
y-direction	3.0 (10.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.2
y-direction	4.5
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-3.0
y-direction	3.2
z-direction	-3.0

Test Article Deflections (m)	
Dynamic	2.4 (7.9 ft)
Permanent	1.8 (5.9 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4 & 11LD2
CDC	11FLEK3 & 11LDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	259 (10.2 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	-29
Max. Pitch Angle (deg)	7
Max. Yaw Angle (deg)	34

Figure 80. Summary of results for test 471470-21.

front of the vehicle impacted post 6. Maximum dynamic deflection of the guardrail was 1.4 m (4.5 ft). The vehicle was traveling parallel to the installation at 38.0 km/h (23.6 mi/h). The front of the vehicle impacted post 7. As the vehicle continued to be redirected, the vehicle began to turn counterclockwise toward the rail because of the orientation of the front tires. The vehicle separated from the guardrail traveling at an estimated exit speed and angle of 25.7 km/h (16.0 mi/h) and 9.5 degrees. The vehicle came to rest 17.3 m (56.7 ft) downstream from the initial point of impact adjacent to the face of the rail element. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 81.

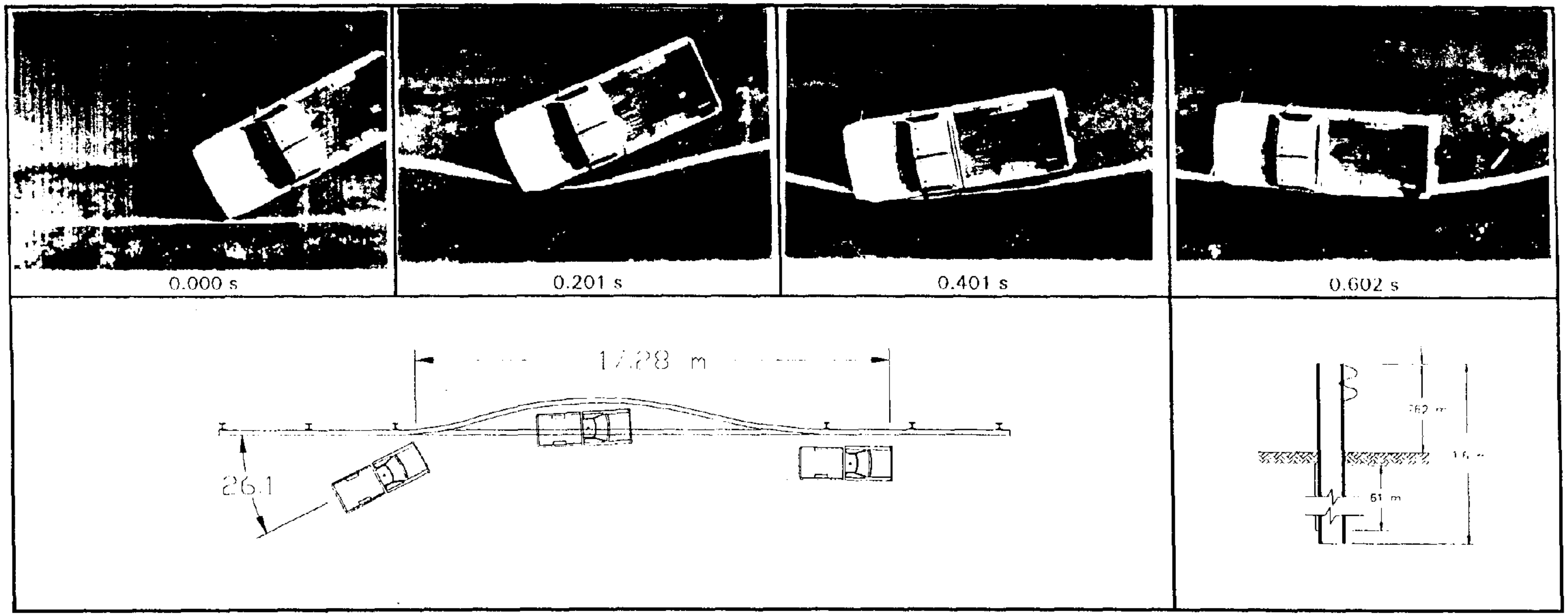
There was evidence of movement on the first 9 posts. The W-beam slipped over the tops of posts 5 through 7, and the maximum permanent deformation of the W-beam was 1.3 m (4.2 ft). The vehicle was in contact with the installation for a total length of 15.7 m (51.7 ft).

Maximum exterior crush at the left front corner at bumper height of the vehicle was 231 mm (9.1 in), and there was no intrusion into or deformation of the occupant compartment. Damage was sustained to the front bumper, grill, hood, and left front lower A-arm assembly. Along the left side the body panels were dented and scraped through the driver's door.

12.5 BOX-BEAM (G3) GUARDRAIL SYSTEM
Test Number 471470-33 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 Chevrolet 2500 Pickup Test inertia weight: 2000 kg (4409 lb) Gross static weight: 2076 kg (4573 lb)	Impact speed: 95.2 km/h (59.1 mi/h) Impact angle: 25.5 degrees

The test installation consisted of a 45.7-m- (150-ft-) long section of the box-beam (G3) guardrail with a 15-m- (49.2-ft-) long telescoping tube terminal (WYBET) on the impact end and a turned down terminal on the downstream end. The vehicle impacted the length-of-need section 0.9 m (2.9 ft) upstream of post 15. As the vehicle impacted the installation, the box-beam rail element began to deflect and redirection of the vehicle began. The right front tire contacted post 15, then post 16, and the wheels began to steer sharply toward the guardrail. The left front tire caught post 17 and post 18. The vehicle became parallel with the installation traveling at 73.0 km/h (45.4 mi/h). Maximum dynamic deflection of the box-beam rail element was 1.15 m (3.8 ft) as the vehicle contacted post 19. The vehicle lost contact with the installation traveling at 44.8 km/h (27.8 mi/h) and an exit angle of approximately 0.7 degree toward the guardrail. As the vehicle exited the installation, it continued to yaw counterclockwise toward the guardrail. The vehicle contacted the guardrail a second time and subsequently came to rest with the nose of the vehicle against the guardrail 26 m (85 ft) down from the initial point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 82.

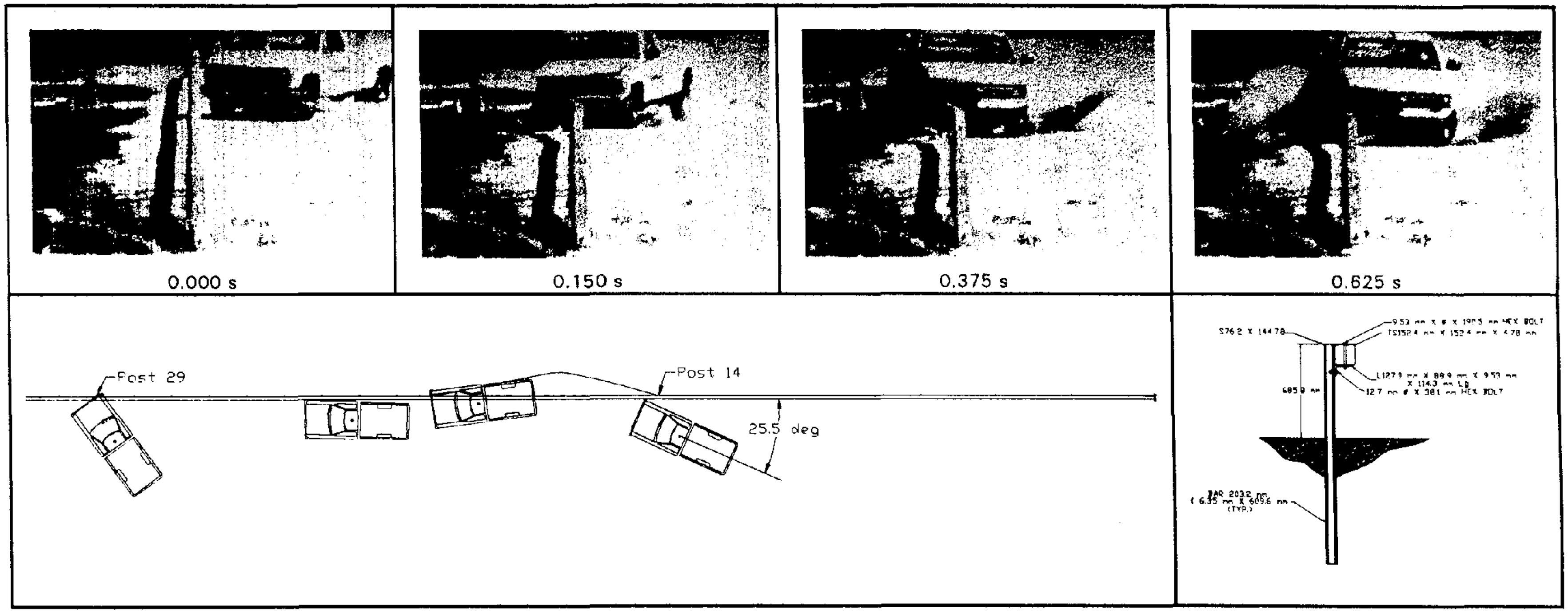


General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-22
Date	1/6/94
Test Article	
Type	Guardrail w/Turned-Down
Name or Manufacturer	Weak-Post W-Beam (G2)
Installation Length (m)	76.2 (250 ft)
Size and/or Dimension and Material of Key Elements	76 cm (30 in) mount ht W-Beam (ARTBA RE-3-73) S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Chevrolet Custom 20
Mass (kg) Curb	2000 (4405 lb)
Test Inertial	2000 (4405 lb)
Dummy	76 (167 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	71.0 (44.1 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	25.7 (16.0 mi/h)
Angle (deg)	9.5
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.6 (14.9 ft/s)
y-direction	3.3 (10.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.8
y-direction	3.1
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-3.1
y-direction	2.6
z-directon	-1.6

Test Article Deflections (m)	
Dynamic	1.4 (4.5 ft)
Permanent	1.3 (4.2 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ3 & 11LD2
CDC	11FLEK2 & 11LDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	231 (9.1 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	9
Max. Pitch Angle (deg)	-3
Max. Yaw Angle (deg)	37

Figure 81. Summary of results for test 471470-22.



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-33
Date	04/13/95
Test Article	
Type	Guardrail
Name or Manufacturer	G3 Box Beam
Installation Length (m)	68 m (223 ft)
Size and/or Dimension and Material of Key Elements	TS6x6x.188 Box Beam on S3x5.7 Steel Posts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1980 (4361 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	95.2 (59.1 mi/h)
Angle (deg)	25.5
Exit Conditions	
Speed (km/h)	44.8 (27.8 mi/h)
Angle (deg)	0.7 toward rail
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.3 (20.7 ft/s)
y-direction	0.9 (3.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-5.8
y-direction	-10.7
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.8
y-direction	2.6
z-direction	-4.1

Test Article Deflections (m)	
Dynamic	1.15 (3.8 ft)
Permanent	0.74 (2.4 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ4
CDC	01FREK2 & 01RYES3
Interior	
OCDI	RF0000000
Maximum Exterior Vehicle Crush (mm)	530 (20.9 in)
Max. Occ. Compart. Deformation (mm)	9 (0.4 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-7
Max. Pitch Angle (deg)	2
Max. Yaw Angle (deg)	-33

Figure 82. Summary of results for test 471470-33.

There were tire marks on the face of the box-beam rail element from posts 15 through 21, and on posts 15 through 20. The box-beam rail element was separated from posts 16 through 20, and these posts were bent at ground level. Lateral deflections occurred at posts 12 through 22. Maximum dynamic deflection of the box-beam rail element was 1.15 m (3.8 ft). Maximum permanent deformation of the installation was 0.74 m (2.4 ft) near post 16. Total length of contact of the vehicle with the installation was 12.6 m (41.3 ft).

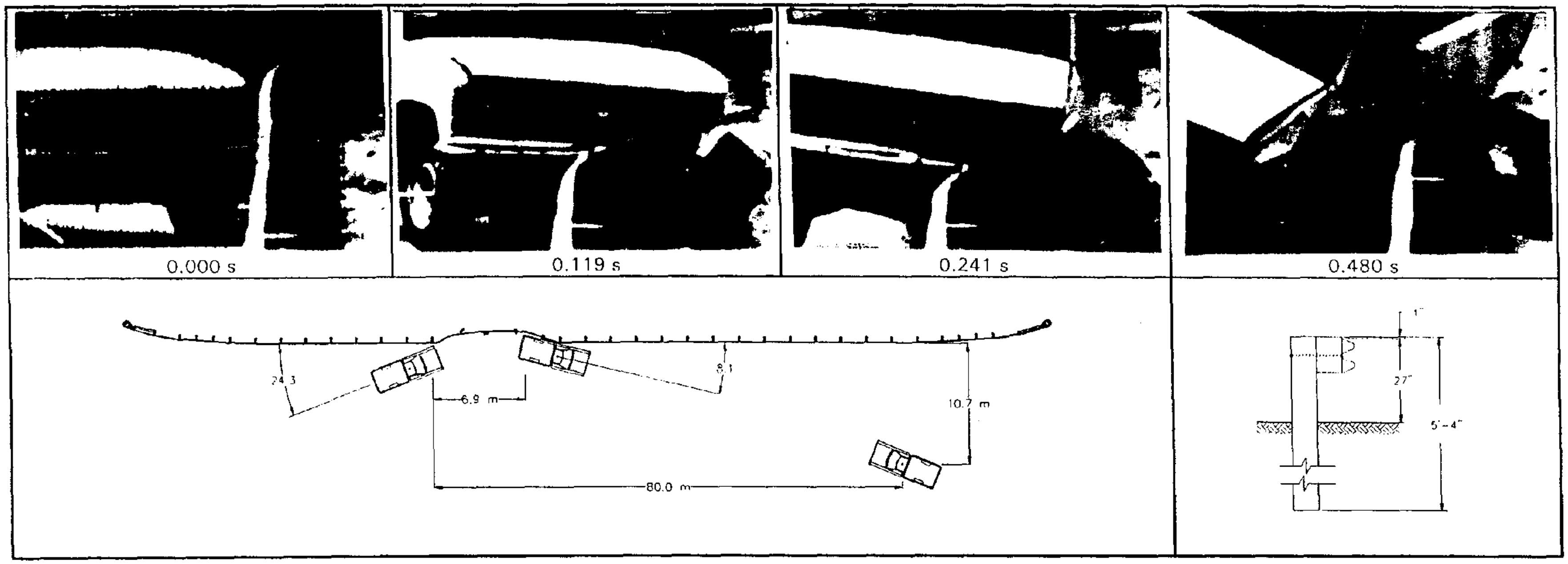
The vehicle's right lower A-arm, stabilizer bar, and tie rod ends on the right side were damaged. The front bumper, grill, right front quarter panel, right door, right rear quarter panel, and the right front wheel were also damaged. Maximum exterior crush at the right front corner of the vehicle was 530 mm (20.9 in), and maximum deformation of the occupant compartment was 9 mm (0.4 in) at the instrument panel area on the passenger side.

12.6 W-BEAM, WOOD-POST (G4(2W)) GUARDRAIL SYSTEM
Test Number 471470-26 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 Chevrolet 2500 Pickup	Impact speed: 100.8 km/h (62.6 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 24.3 degrees
Gross static weight: 2074 kg (4568 lb)	

The test installation consisted of a 45.7-m- (150-ft-) long section of the standard G4(2W) guardrail with a MELT at the upstream end and a standard breakaway cable terminal (BCT) at the downstream end, for a total installation length of 68.6 m (225 ft). The vehicle impacted the length-of-need section 0.61 m (2 ft) upstream of post 14, or 4.5 m (14.5 ft) upstream of the splice at post 16. As the vehicle impacted the guardrail, the W-beam rail element began to deform and post 14 began to displace laterally. The vehicle impacted post 14 shortly afterwards, and redirection of the vehicle began. The front of the vehicle contacted post 15 and then the tire contacted the post. The vehicle contacted post 16 and the tire contacted post 16. Shortly after that, the left front wheel assembly separated from the vehicle and the blockout on post 16 split. The rear of the vehicle made contact with the guardrail. The vehicle contacted post 17 and the vehicle was parallel with the installation traveling at 74.3 km/h (46.3 mi/h). Maximum deflection of the W-beam rail of 0.82 m (2.7 ft) occurred near post 16. The vehicle lost contact with the installation traveling at a speed of 70.8 km/h (44.0 mi/h) and at an exit angle of 8.1 degrees. As the vehicle exited the rail, it had rolled 25 degrees counterclockwise and was yawing clockwise. Maximum roll angle attained was 39 deg. As the damaged front end of the vehicle contacted the ground, the vehicle righted itself and began to yaw counterclockwise, subsequently coming to rest 80 m (263 ft) downstream and 10.7 m (35 ft) forward of the point of impact. The vehicle had yawed approximately 150 degrees. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 83.

The bolts were pulled out of the W-beam rail element at posts 15 and 16, and the blockout on post 16 was split. None of the posts broke off, but some posts were pushed back. The W-beam rail element was deformed from posts 13 through 18 and there was evidence of tire contract with posts 14 through 17. Maximum dynamic deflection of the



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-26
Date	05/25/94
Test Article	
Type	Guardrail
Name or Manufacturer	G4(2W)
Installation Length (m)	69 m (225 ft)
Size and/or Dimension and Material of Key Elements	G4(2W) Guardrail System with MELT End Terminals
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1849 (4073 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2074 (4568 lb)

Impact Conditions	
Speed (km/h)	100.8 (62.6 mi/h)
Angle (deg)	24.3
Exit Conditions	
Speed (km/h)	70.8 (44.0 mi/h)
Angle (deg)	8.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.5 (24.5 ft/s)
y-direction	5.9 (19.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-11.6
y-direction	11.4
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.1
y-direction	6.8
z-direction	9.1

Test Article Deflections (m)	
Dynamic	0.82 (2.7 ft)
Permanent	0.69 (2.25 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ5
CDC	11FLEK2 & 11LDLW4
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm)	370 (14.6 in)
Max. Occ. Compart. Deformation (mm)	44 (1.7 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-40
Max. Pitch Angle (deg)	-12
Max. Yaw Angle (deg)	47

Figure 83. Summary of results for test 471470-26.

guardrail during the test was 0.82 m (2.7 ft) near post 16. Maximum permanent deformation of the guardrail was 0.69 m (2.25 ft) between posts 15 and 16. The vehicle was in contact with the guardrail system for a total length of 6.9 m (22.7 ft).

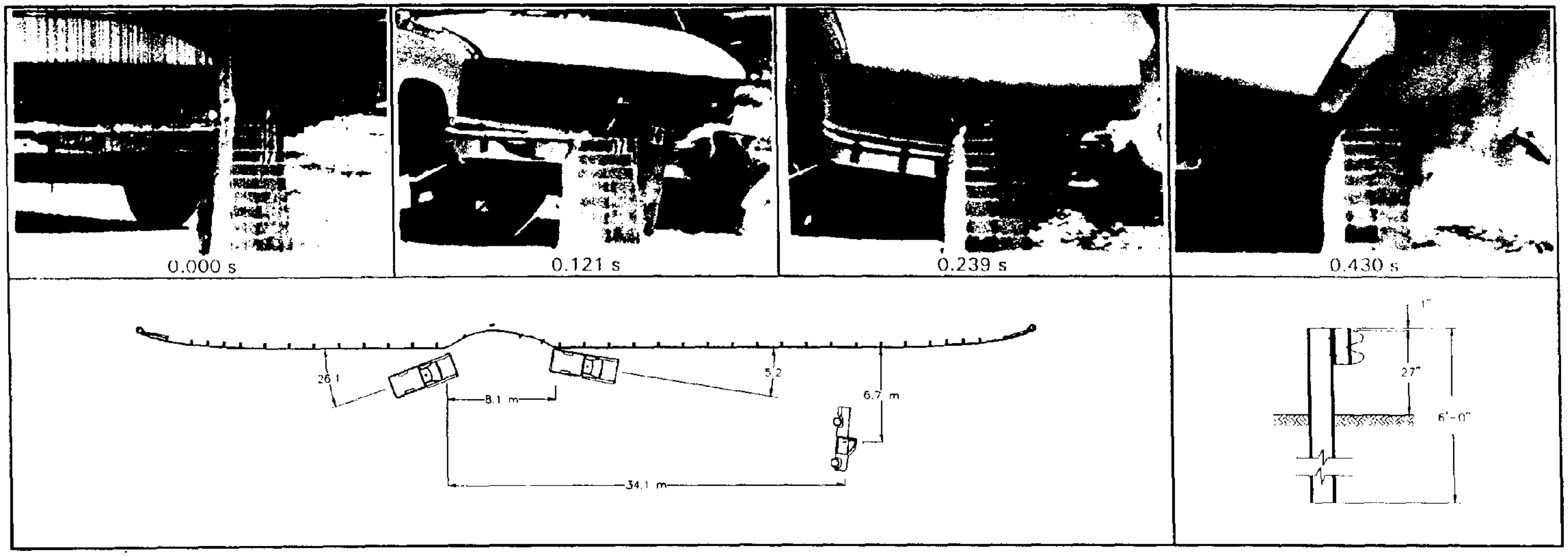
The vehicle's stabilizer bar, upper and lower A-arms, and tie rods on the left side were damaged and the frame at the left front was bent. The left front spindle, wheel, and tire were separated from the vehicle. The front bumper, grill, and entire left side were also damaged. Maximum exterior crush at the left front corner of the vehicle was 370 mm (14.6 in) at bumper height. There was 44 mm (1.7 in) deformation of the occupant compartment in the floor pan area near the transmission tunnel.

12.7 W-BEAM, STEEL-POST (G4(1S)) GUARDRAIL SYSTEM Test Number 471470-27 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1988 Chevrolet 2500 Pickup	Impact speed: 101.4 km/h (62.6 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 26.1 degrees
Gross static weight: 2075 kg (4570 lb)	

The test installation consisted of a 45.7-m- (150-ft-) long section of the standard G4(1S) guardrail with a MELT at the upstream end and a standard BCT at the downstream end, for a total installation length of 68.6 m (225 ft). The vehicle impacted the length-of-need section 0.61 m (2 ft) upstream of post 14, or 4.5 m (14.5 ft) upstream of the splice at post 16. As the vehicle impacted the guardrail, the W-beam rail element began to deform, and posts 13 and 14 began to displace laterally. The front of the vehicle impacted post 14 shortly thereafter, the left front tire of the vehicle contacted post 15, and, as the vehicle continued forward, the tire aired out and began to fold under. Redirection of the vehicle began as the body of the vehicle began to bow upward in the center (between the cab and bed). The left front tire snagged on post 16 and the body of the vehicle began to bow substantially. The rear of the vehicle made contact with the W-beam rail and then the vehicle was parallel with the installation traveling at 66.0 km/h (41.0 mi/h). As the vehicle traveled past post 17, the left front tire made slight contact with the post. Maximum deflection of the W-beam rail was 1.01 m (3.3 ft). The vehicle lost contact with the installation traveling at a speed of 58.7 km/h (36.5 mi/h) and at an exit trajectory of 5.2 degrees. As the vehicle exited the rail, it had rolled 28 degrees counterclockwise and was yawing clockwise. As the damaged front end of the vehicle contacted the ground, the vehicle continued to roll onto its left side and subsequently slid to rest on its left side 34 m (112 ft) downstream and 6.7 m (22 ft) forward of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 84.

The MELT anchor on the upstream end had pulled up slightly and moved laterally 44.5 mm (1.75 in). The buffered end nose was pulled off the end post (post 1). The bolts were pulled out of the W-beam rail element at posts 15, 16, and 17, and the posts and blockouts were bent. All the steel posts upstream of impact were disturbed with measurable displacements. The W-beam rail element was deformed between posts 14 through 18 and there was evidence of tire contract with posts 15 through 17. Maximum dynamic deflection



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-27
Date	06/09/94
Test Article	
Type	Guardrail
Name or Manufacturer	G4(1S)
Installation Length (m)	69 m (225 ft)
Size and/or dimension and material of key elements	G4(2W) Guardrail System with MELT End Terminals
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1988 Chevrolet 2500
Mass (kg) Curb	1944 (4282 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2075 (4570 lb)

Impact Conditions	
Speed (km/h)	101.4 (63.0 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	58.7 (36.5 mi/h)
Angle (deg)	5.2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.5 (24.8 ft/s)
y-direction	4.9 (16.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-7.8
y-direction	6.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.0
y-direction	4.7
z-direction	3.9

Test Article Deflections (m)	
Dynamic	0.91 (3.0 ft)
Permanent	0.64 (2.1 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ6 9L&T3
CDC	11FLEK3 & 00LDAO3
Interior	
OCDI	LF0100000
Maximum Exterior Vehicle Crush (mm)	570 (22.4 in)
Max. Occ. Compart. Deformation (mm)	53 (2.1 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-119
Max. Pitch Angle (deg)	-19
Max. Yaw Angle (deg)	79

Figure 84. Summary of results for test 47147-27.

of the guardrail during the test was 1.01 m (3.3 ft). Maximum permanent deformation of the guardrail was 0.73 m (2.4 ft) between posts 15 and 16. The vehicle was in contact with the guardrail system for a total length of 8.1 m (26.5 ft).

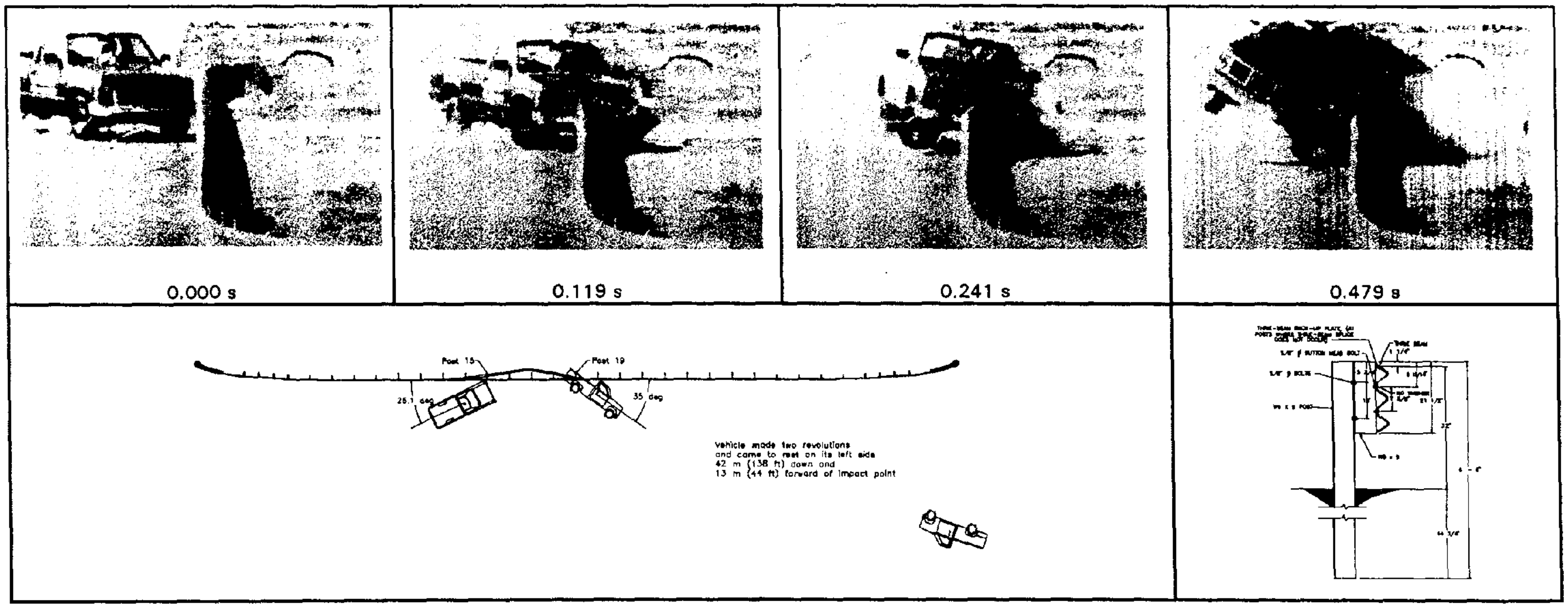
The vehicle's stabilizer bar, upper and lower A-arms, and tie rods on the left side were damaged and the frame at the left front was bent. The left front spindle, wheel, and tire were damaged. The front bumper, grill, hood, radiator, windshield, and entire left side also were damaged. Maximum exterior crush at the left front corner of the vehicle was 570 mm (22.4 in) at bumper height. There was 53 mm (2.1 in) deformation of the occupant compartment in the floor pan area on the driver's side.

12.8 THRIE-BEAM (G9) GUARDRAIL SYSTEM
Test Number 471470-31 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1990 GMC 2500 Pickup	Impact speed: 102.5 km/h (63.5 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 26.1 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of a 30.5-m- (100-ft-) long length-of-need section of the standard thrie-beam (G9) guardrail with a 1.9-m- (6-ft, 3-in-) long transition section from the thrie-beam to the W-beam rail element, a 3.8-m- (12-ft, 6-in-) long section of standard steel-post, W-beam G4(1S) guardrail and a 11.4-m- (37-ft, 6-in-) long MELT at each end, for a total installation length of 64.8 m (212 ft, 6 in). The vehicle impacted the length-of-need section 102 mm (4.0 in) upstream of post 15. As the vehicle impacted the installation, the thrie-beam rail element began to deflect and redirection of the vehicle began. The left front wheel began to steer sharply toward the guardrail, and posts 16 and 17 began to rotate about their vertical axes. The left front tire caught the flanges of post 16 and post 17. Maximum dynamic deflection of the thrie-beam rail element of 1.07 m (3.5 ft) occurred between posts 17 and 18. The vehicle became parallel with the installation traveling at 67.5 km/h (41.9 mi/h). The rear of the vehicle contacted the thrie-beam rail element. The vehicle lost contact with the installation traveling at a speed of 54.5 km/h (33.9 mi/h), an exit angle of approximately 35 degrees, and a roll angle of roughly -45 degrees. As the vehicle exited the installation, it continued to roll counterclockwise and yaw clockwise. The vehicle rolled two and a quarter revolutions and came to rest on its left side 42 m (138 ft) down and 13 m (44 ft) forward of the initial point of impact, with the front of the vehicle facing the direction of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 85.

There were tire marks on the face of the thrie-beam rail element from posts 15 through 19, and on the face of posts 16 and 17. The thrie-beam rail element was separated from post 16 and the flanges on post 17 showed evidence of wheel contact. Posts 15 through 19 were twisted severely. The lateral deflections occurred at posts 13 through 20. Maximum dynamic deflection of the thrie-beam rail element was 1.07 m (3.5 ft). Maximum permanent



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-31
Date	04/14/95
Test Article	
Type	Guardrail
Name or Manufacturer	G9 Thrie Beam
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Thrie Beam on W6x9 Posts with M14x17.2 Blockouts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1990 GMC 2500
Mass (kg) Curb	2094 (4612 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	102.2 (63.5 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	54.5 (33.9 mi/h)
Angle (deg)	approx. 35
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	8.0 (26.4 ft/s)
y-direction	4.9 (16.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-7.0
y-direction	6.3
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.4
y-direction	4.5
z-direction	-3.3

Test Article Deflections (m)	
Dynamic	1.07 (3.5 ft)
Permanent	0.64 (2.1 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4 & 9L&T5
CDC	11FLEK2 & 80TZDO5
Interior	
OCDI	RF0200000
Maximum Exterior Vehicle Crush (mm)	420 (16.5 in)
Max. Occ. Compart. Deformation (mm)	114 (4.5 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-810
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	221

Figure 85. Summary of results for test 471470-31.

deformation of the installation was 0.64 m (2.1 ft) just upstream of post 17. Total length of contact of the vehicle with the installation was 8.2 m (26.8 ft).

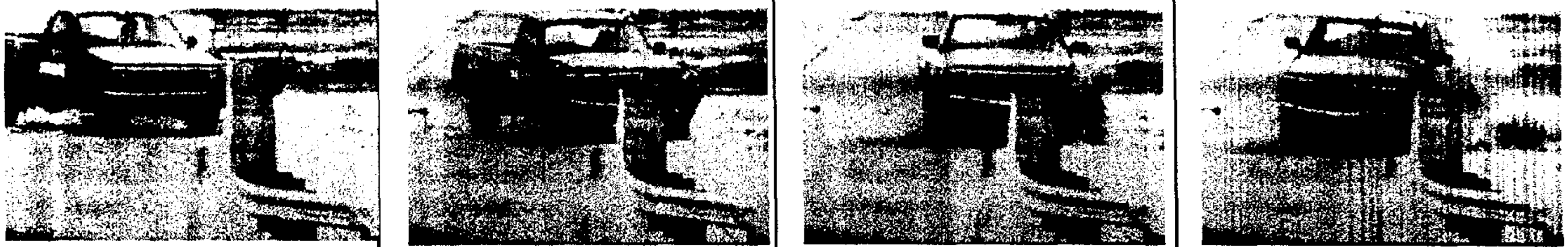
The vehicle's upper and lower A-arms, stabilizer bar, frame, and tie rod ends on the left side were damaged. The front bumper, grill, hood, left front quarter panel, both doors, and the left front and rear wheels were also damaged. The windshield and windows were broken and the roof was damaged because of the rollover. Maximum exterior crush at the left front corner of the vehicle was 420 mm (16.5 in) and maximum deformation of the occupant compartment was 144 mm (4.5 in) downward from the roof area on the passenger side.

12.9 MODIFIED THRIE-BEAM GUARDRAIL SYSTEM
Test Number 471470-30 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 GMC 2500 Pickup	Impact speed: 100.2 km/h (62.3 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 25.1 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of a 30.5-m- (100-ft-) long length-of-need section of the modified thrie-beam guardrail with a 1.9-m- (6-ft, 3-in-) long transition section from the thrie-beam to the W-beam rail element, a 3.8-m- (12-ft, 6-in-) long section of standard steel-post, W-beam G4(1S) guardrail and a 11.4-m- (37-ft, 6-in-) long MELT at each end for a total installation length of 64.8 m (212 ft, 6 in). The vehicle impacted the length-of-need section at post 15. As the vehicle impacted the installation, the thrie-beam guardrail began to deflect and redirection of the vehicle began. The left front tire made contact with the flange and face of post 16, which caused the wheel to turn outward (or counterclockwise). The vehicle continued forward as posts 17 and 18 began to rotate about their vertical axes. The left front wheel assembly caught the flange at post 17 and the entire wheel assembly was torn from the axle. The front of the vehicle reached post 18 and the rear of the vehicle made contact with the thrie-beam rail element. The vehicle became parallel with the installation traveling at 74.3 km/h (46.2 mi/h). The vehicle lost contact with the installation traveling at a speed of 67.4 km/h (41.9 mi/h) and an exit angle of approximately 11.1 degrees. The vehicle brakes were applied as the vehicle exited the test area, and subsequently came to rest 49 m (160 ft) down and 6 m (19 ft) behind the initial point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 86.

There were tire marks on the face of the thrie-beam rail element from posts 15 through 19, and on the face of post 16 and the back side of post 17. The thrie-beam rail element was separated from post 17 and the flanges on post 17 showed evidence of wheel contact. Posts 16, 17, and 18 were twisted severely. Lateral deflections occurred at posts 14 through 20. Maximum dynamic deflection of the thrie-beam rail element was 1.02 m (3.4 ft). Maximum permanent deformation of the installation was 0.61 m (2.0 ft) just upstream of post 17. Total length of contact of the vehicle with the installation was 8.0 m (26.1 ft).



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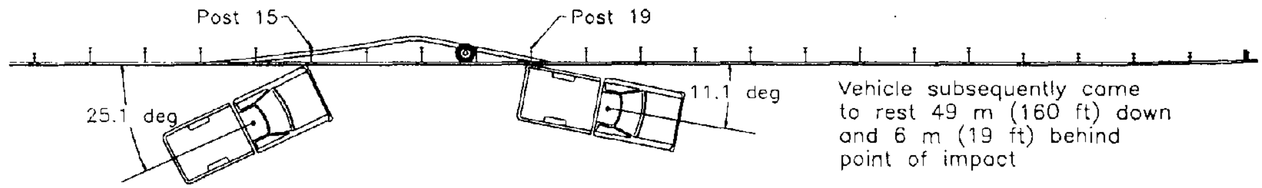
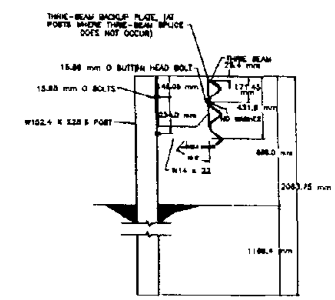




General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-30
Date	01/11/95
Test Article	
Type	Guardrail
Name or Manufacturer	Modified Thrie beam
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Thrie Beam on W6x9 Post and M14x18 Spacer with Cutout
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 GMC 2500 Pickup
Mass (kg) Curb	2043 (4500 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	100.2 (62.3 mi/h)
Angle (deg)	25.1
Exit Conditions	
Speed (km/h)	67.4 (41.9mi/h)
Angle (deg)	11.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.8 (25.6 ft/s)
y-direction	5.2 (17.1 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-9.7
y-direction	9.0
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.2
y-direction	5.2
z-direction	-2.9

Test Article Deflections (m)	
Dynamic	1.02 (3.4 ft)
Permanent	0.61 (2.0 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LYEW4
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	430 (16.9 in)
Max. Occ. Compart. Deformation (mm)	16 (0.6 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-9
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	36

Figure 86. Summary of results for test 471470-30.

The vehicle's upper and lower A-arms, stabilizer bar, frame, tie rod ends, and spindle on the left side were damaged. The left front wheel assembly was torn from the vehicle's axle. The front bumper, grill, left front quarter panel, and both doors were also damaged. Maximum exterior crush at the left front corner of the vehicle was 430 mm (16.9 in) and there was deformation at the floor pan area of 16 mm (0.6 in).

12.10 SUMMARY OF FINDINGS

12.10.1 Cable (G1) Guardrail System

The vehicle was successfully contained and smoothly redirected by the cable (G1) guardrail system under test level 3 conditions. The maximum dynamic deflection of the guardrail was 2.4 m (7.8 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained moderate damage with no intrusion or deformation into the passenger compartment. The vehicle remained upright and stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of 2.0 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the cable (G1) guardrail system was considered satisfactory according to guidelines set forth in NCHRP Report 350, as shown in table 32.

It should be noted that the impact speed of 95.1 km/h (59.1 mi/h) was lower than the target impact speed of 100 km/h (62.2 mi/h). However, the impact angle of 26.7 degrees was higher than the target impact angle of 25 degrees. Consequently, the impact severity (IS) value of the test was 141.2 kJ (104.1 kip-ft), which was actually higher than the nominal IS value of 138.1 kJ (101.9 kip-ft) for the target impact speed and angle. Furthermore, based on the test results, there is no reason to believe that the cable (G1) guardrail system would perform any differently at the target impact speed and angle.

12.10.2 W-Beam, Weak-Post (G2) Guardrail System

The W-beam, weak-post (G2) guardrail system was crash tested under both test level 3 (test no. 471470-21) and test level 2 (test no. 471470-22) conditions. Summaries of the results of the two tests are shown in tables 33 and 34, respectively.

The W-beam, weak-post (G2) guardrail system failed to contain and redirect the impacting vehicle at test level 3 conditions. The left front, left rear, and right front tires of the vehicle overrode the guardrail and exited only when the end of the guardrail installation was reached. It is evident from reviewing the high-speed film that, had there been a longer run of guardrail, the vehicle would likely have vaulted over the guardrail completely, which is not acceptable. The best scenario is for the vehicle to straddle the guardrail until it comes to rest.

Table 32. Assessment of results of test with cable (G1) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-28 | Test Date: 11/15/94

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle. The vehicle did not penetrate or go over the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to pose any undue hazard to adjacent traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal if any intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.3 m/s Longitudinal Ridedown Acceleration = -4.0 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 2 degrees, which was less than 60 percent of the test impact angle of 26.7 degrees.	Pass

Table 33. Assessment of results of test with W-beam, weak-post (G2) guardrail system (test level 3).

Test Agency: Texas Transportation Institute | Test No.: 471470-21 | Test Date: 09/09/93

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The left front, left rear, and right front tires of the vehicle overrode the guardrail before reaching the end of the test installation.	Fail
Occupant Risk D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	The only debris to separate a significant distance from the installation were the washers used in attaching the W-beam to the posts. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable throughout the test period; however, it did mount the installation.	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was no vehicle intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.9 m/s Longitudinal Ridedown Acceleration = -4.2 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle remained on top of the guardrail until the end of the installation.	Pass

Table 34. Assessment of results of test with W-beam weak-post (G2) guardrail system (test level 2).

Test Agency: Texas Transportation Institute | Test No.: 471470-22 | Test Date: 01/06/94

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was no detached elements or debris to pose any undue hazard to adjacent traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was no vehicle intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.6 m/s Longitudinal Ridedown Acceleration = -4.8 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle of 9.5 degrees was less than 60 percent of the test impact angle.	Pass

Otherwise, the G2 guardrail system performed well with respect to the other evaluation criteria. There were no debris or detached elements from the installation that would pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact though it was astride the guardrail. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic. The occupant risk factors were all well within the desirable limits set forth in NCHRP Report 350.

The W-beam, weak-post (G2) guardrail system successfully contained and redirected the impacting vehicle under test level 2 conditions. There were no debris or detached elements from the installation that would pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic. The occupant risk factors were all well within the desirable limits set forth in NCHRP Report 350.

In summary, the impact performance of the W-beam, weak-post (G2) guardrail system was considered unsatisfactory from the structural adequacy standpoint under NCHRP Report 350 test level 3 conditions, but performed satisfactorily under test level 2 conditions.

12.10.3 Box-Beam (G3) Guardrail System

The box-beam (G3) guardrail system successfully contained and redirected the vehicle. The maximum dynamic deflection of the guardrail was 1.15 m (3.8 ft). There were no detached elements or debris to exhibit an undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation into the passenger compartment. The vehicle remained upright and stable during the impact sequence and after exiting the guardrail. The trajectory of the vehicle was judged to have posed minimal, if any, potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of approximately 0.7 degree toward the guardrail. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350.

The impact speed of 95.2 km/h (59.1 mi/h) was slightly slower than the lower tolerance limit of 96 km/h (59.7 mi/h) (i.e., for a nominal impact speed of 100 km/h (62.2 mi/h) and a tolerance of -4 km/h (-2.5 mi/h)). The impact angle of 25.5 degrees was higher than the nominal impact angle of 25 degrees. The resulting IS of 129.6 kJ (95.6 kip-ft) was above the lower IS tolerance limit of 127.3 kJ (93.9 kip-ft) (i.e., for a nominal IS of 138.1 kJ (101.9 kip-ft) and a tolerance of -10.8 kJ (-8.0 kip-ft)). Furthermore, there is no reason to believe that the box-beam (G3) guardrail system would have performed any differently with a slightly higher impact speed.

In summary, the impact performance of the box-beam (G3) guardrail system was considered satisfactory according to evaluation criteria set forth in NCHRP Report 350, as shown in table 35.

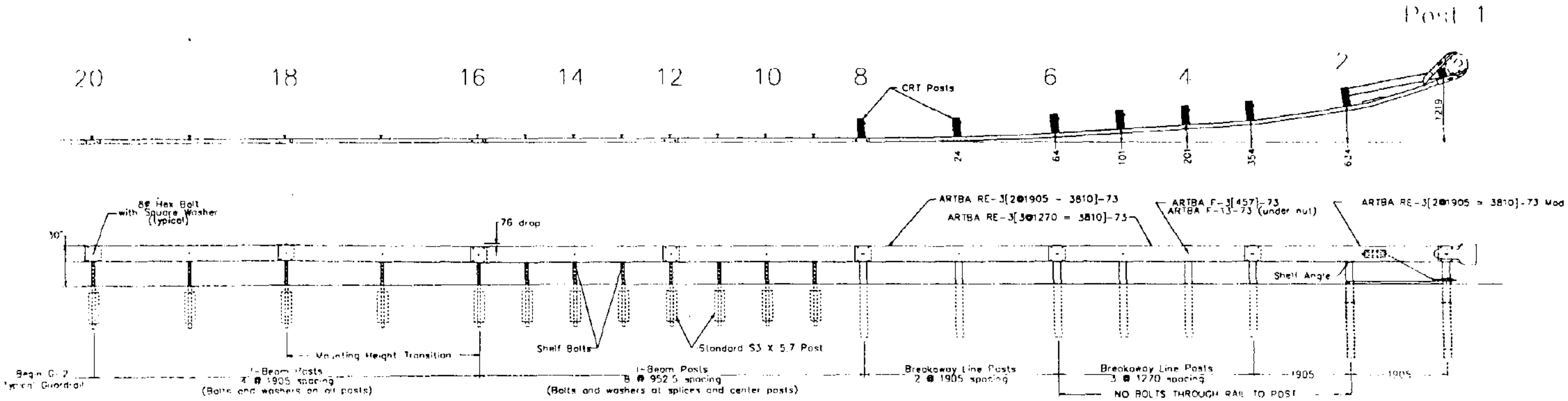


Figure 62. Details of the modified mini-MELT for the weak-post G2 guardrail system used for tests 471470-24 and 471470-25.

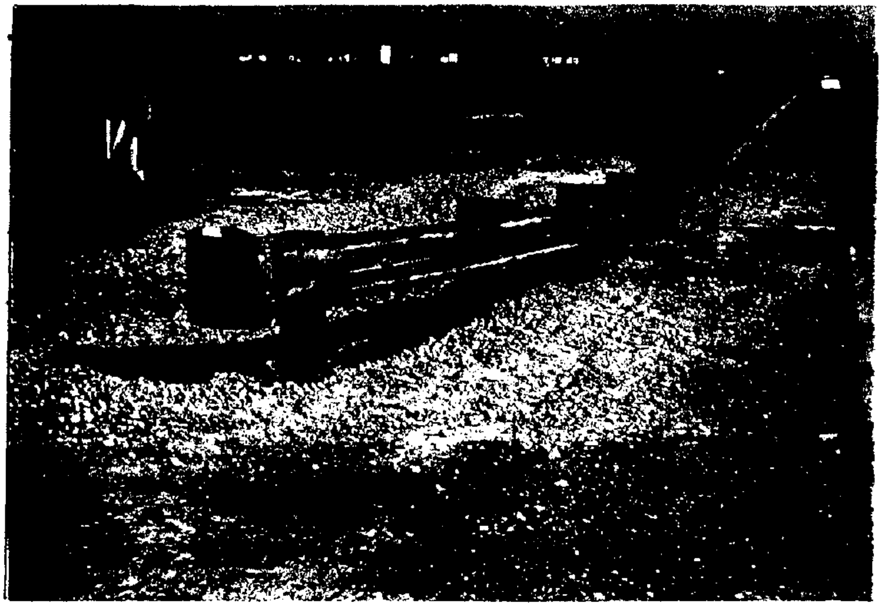


Figure 63. Modified mini-MELT used in tests 471470-24 and 471470-25.

The end of the terminal was flared 1.22 m (4 ft) from the tangent section of the guardrail and the parabolic flare was effected over the first 11.4 m (37 ft, 6 in), with offsets of 1.22, 0.63, 0.34, 0.20, 0.10, 0.06, and 0.024 m (4.0, 2.08, 1.16, 0.66, 0.33, 0.21, and 0.08 ft) for posts 1 through 8, respectively. Note that the first two 3.8-m (12-ft, 6-in) sections of W-beam rail elements were shop curved to accommodate the parabolic curve, with a nominal radius of 11.6 m (38 ft) for the first section and 27.4 m (90 ft) for the second section.

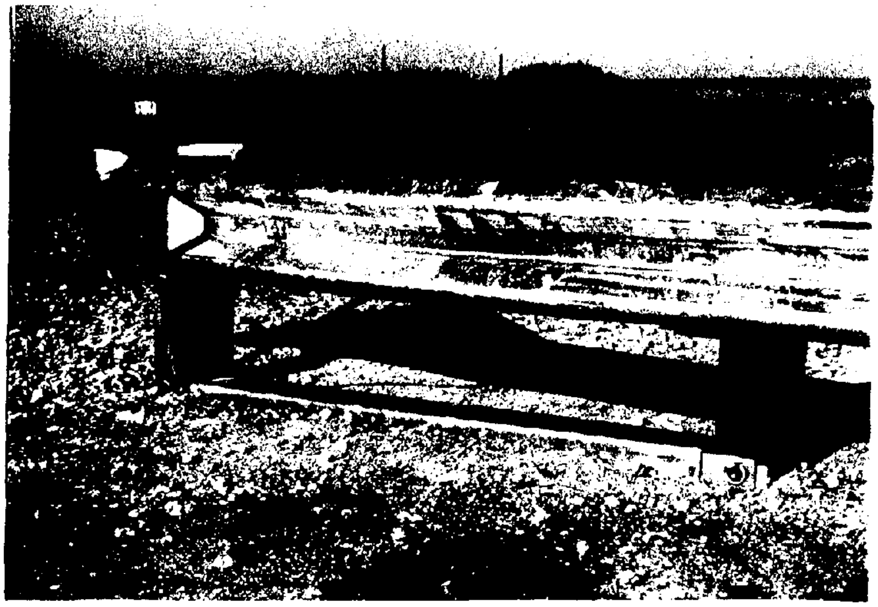
The buffered nose piece had two bolted-on diaphragms similar to the standard MELT. Posts 1 (end post) and 2 were BWPs installed in 1525-mm- (5-ft-) long, TS 152-mm × 203-mm × 4.8-mm (6-in × 8-in × 3/16-in) steel foundation tubes with 460-mm × 610-mm × 6-mm (18-in × 24-in × 1/4-in) soil plates. A 160-mm × 50-mm (6-in × 2-in) channel strut connected the two foundation tubes at ground level for increased anchorage capacity. The posts were 1.1-m (43-in) long with cross-sectional dimensions of 140 mm × 191 mm (5-1/2 in × 7-1/2 in). A 60.3-mm- (2-3/8-in-) diameter hole was drilled through the post at ground level to facilitate breaking of the post upon impact. The post bolt hole of the end post was slotted with the dimensions of 19.1 mm × 63.5 mm (3/4 in × 2-1/2 in). Post 2 was not bolted to the W-beam rail element, but rested on a shelf angle attached to the post. The bearing plate for the cable anchor was modified with two 3.45-mm- (0.136-in-) diameter holes drilled 127 mm (5 in) apart and 38.1 mm (1-1/2 in) from the top to allow attachment of the bearing plate to the end post with galvanized nails. Photographs showing the details for posts 1 and 2 are shown in figure 64.

Posts 3 through 8 in the terminal section were 1.8-m- (6-ft-) long wooden CRT posts. The W-beam rail elements were not bolted onto posts 3 through 6. In other words, the W-beam rail elements were bolted at the end post (post 1) and then the next bolted post was post 7 for an unsupported rail length of 9.5 m (31 ft, 3 in). However, it should be noted that the rail element was supported by a shelf angle at the second post (post 2). Standard 1.6-m- (5-ft, 3-in-) long S3×5.7 steel posts with 203-mm × 610-mm × 6-mm (8-in × 24-in × 1/4-in) soil plates posts were used starting at post 9 with eight spans at 0.95 m (3 ft, 1-1/2 in) and then four spans at 1.9 m (6 ft, 3 in) for the transition area. The standard 3.8-m (12-ft, 6-in) spacing was used throughout the remaining G2 guardrail system. The height of the railing dropped 76 mm (3 in) over the 3.8-m (12 ft, 6 in) transition area from post 16 to post 18 (i.e., the height of the rail at post 18 was 762 mm (30 in) and the height of the rail at post 16 was 686 mm (27 in)). Photographs showing the details at posts 1 through 8 are shown in figure 65, and posts 9 through 20 are shown in figure 66.

11.2 TEST NUMBER 471470-20 (NCHRP REPORT 350 TEST DESIGNATION 3-35)

Test vehicle: 1985 Dodge 250 Ram Pickup	Impact speed: 101.8 km/h (63.3 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 20.8 degrees
Gross static weight: 2076 kg (4577 lb)	

The vehicle impacted the terminal at post 4 (the beginning of the length of need) or 7.62 m (25 ft) downstream from the end post. As the vehicle impacted the terminal, the



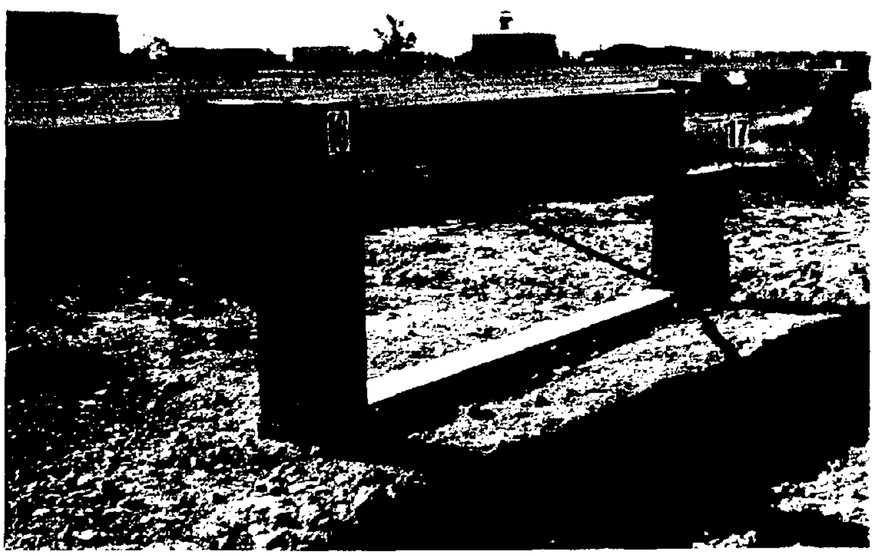
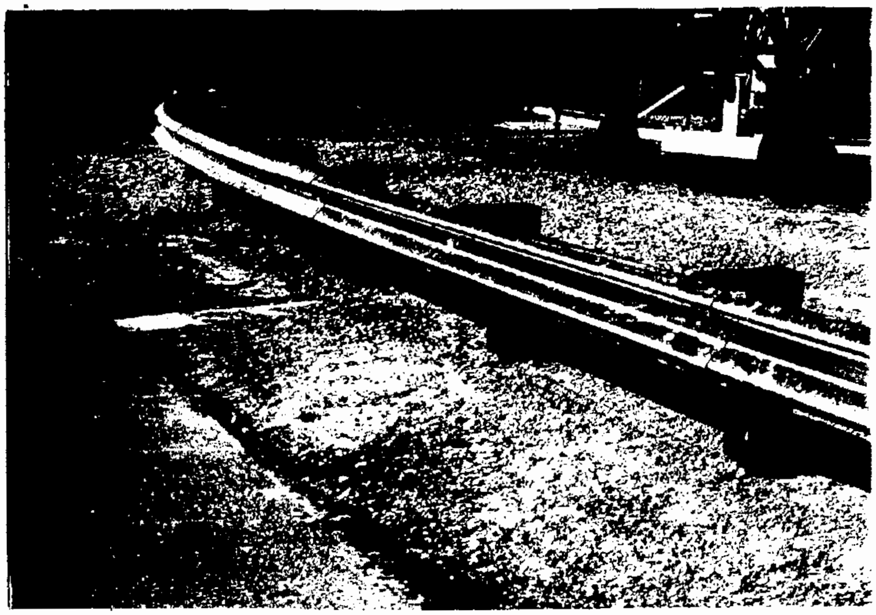


Figure 64. Modified mini-MELT posts 1 and 2 before tests 471470-24 and 25.



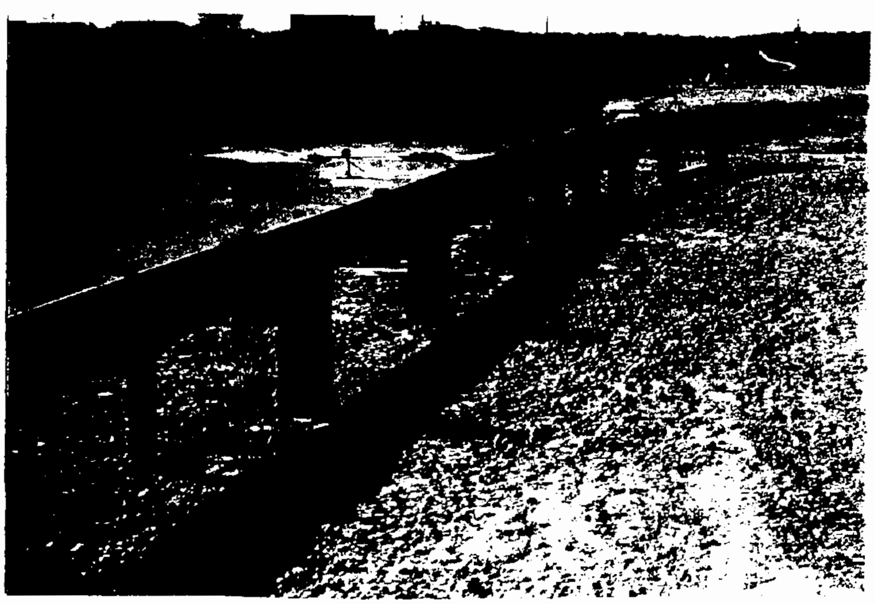


Figure 65. Posts 1 through 8 of the modified mini-MELT before tests 471470-24 and 25.

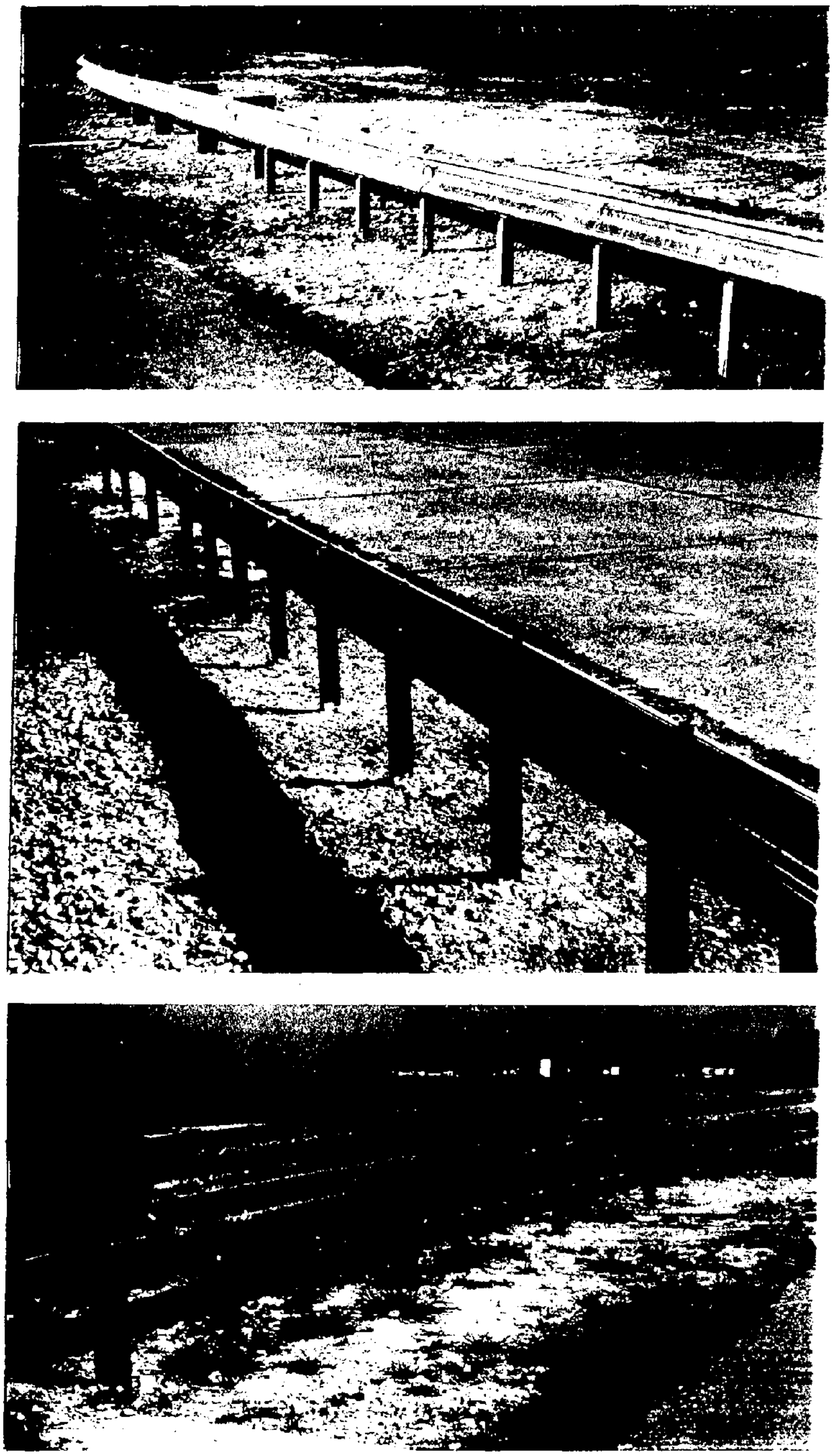


Figure 66. Posts 9 through 20 before tests 471470-24 and 25.

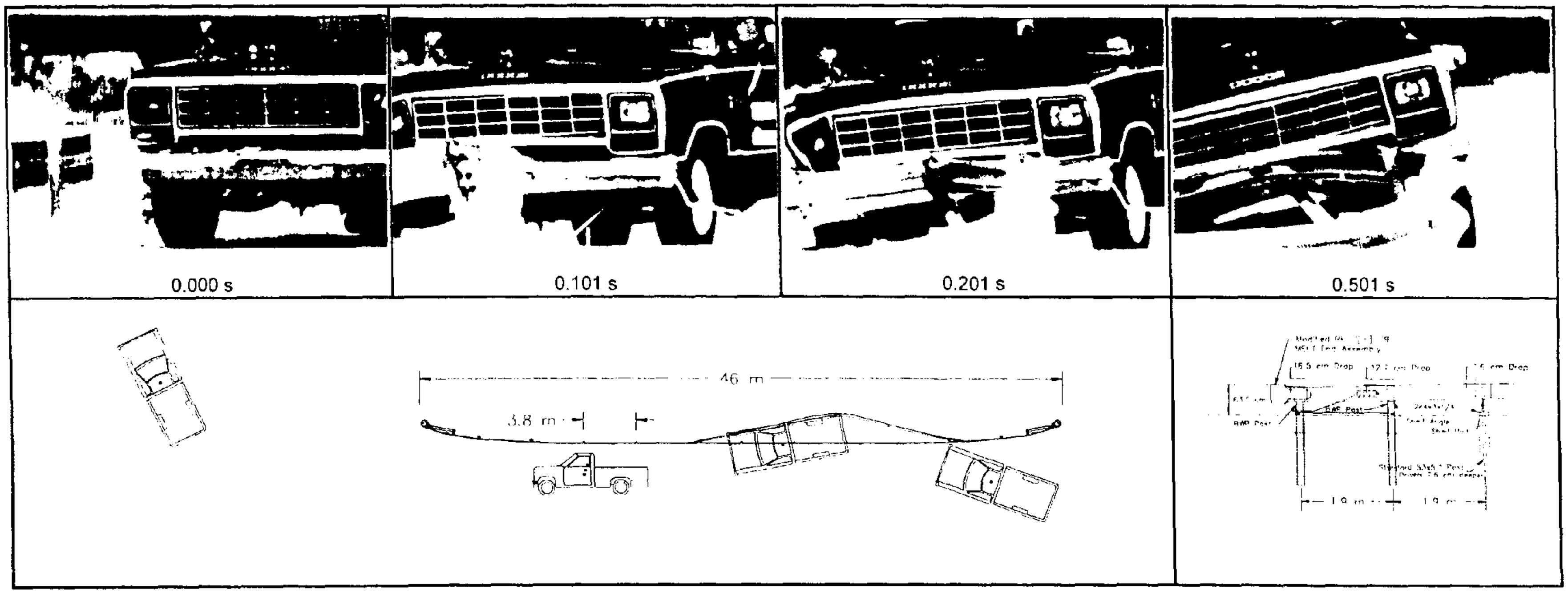
W-beam rail element began to deform, and the vehicle began to redirect. As the vehicle continued forward, the W-beam rail element rode over the top of the posts as the W-beam deformed along the path of the vehicle. The right front tire rode over post 5, causing the post to fracture just above the soil plate. The rear of the vehicle contacted the guardrail and the vehicle was traveling parallel to the installation at 78.4 km/h (48.7 mi/h). Maximum dynamic deflection of the guardrail was 2.0 m (6.7 ft). As the vehicle was being redirected, the W-beam rail element dropped and began to dig into the ground. The vehicle began to roll clockwise and the rear of the vehicle began to rise significantly. The vehicle was airborne and continued to roll clockwise as it lost contact with the installation. Shortly after that, the vehicle landed on its right side, bounced, and righted itself. The vehicle came to rest upright 90 m (296 ft) downstream and 9 m (31 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 67.

Posts 1 through 11 were displaced laterally and post 5 fractured just above the top of the soil plate. The W-beam rail element had slipped over the tops of post 4 through 8 and the maximum permanent deformation of the W-beam rail element was 1.7 m (5.5 ft). The vehicle was in contact with the installation for 25 m (81 ft). The vehicle sustained damage to the right side. The front bumper, grill, and hood were damaged and the entire right side of the body was dented and scraped. Maximum exterior crush at the right front corner at bumper height of the vehicle was 330 mm (13.0 in). There was no intrusion or deformation of the occupant compartment.

11.3 TEST NUMBER 471470-23 (NCHRP REPORT 230 TEST DESIGNATION S31)

Test vehicle: 1984 Cadillac Fleetwood	Impact speed: 97.3 km/h (60.5 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.4 degrees
Gross static weight: 2117 kg (4662 lb)	

The vehicle impacted the guardrail in the reverse direction (i.e., opposite to normal direction of travel) 4.6 m (15 ft) upstream of the last wooden post of the terminal (post 5), or 0.76 m (2 ft, 6 in) upstream of post 3. Note that the numbering system of the posts for this crash test was different from that of the other crash tests (i.e., the end post was numbered post 12, the second post numbered post 11, etc.). As the vehicle impacted the guardrail, the W-beam rail element began to deform and post 3 began to displace laterally. The front tire of the vehicle impacted post 3 and then post 4. The W-beam rail element ruptured at the splice at post 5 (last wood post of the terminal section). Just before the rupture, the rail element had deflected 0.3 m (1.09 ft), but post 5 did not deflect laterally. The vehicle impacted the end of the ruptured rail and post 5 while the vehicle was traveling at 85.3 km/h (53.0 mi/h). The W-beam rail was loaded axially, the bolt in post 6 pulled out, and subsequently the rail element buckled at the post 6 location. The axial loading and longitudinal movement of the W-beam rail element caused the end post (post 12) to fracture just above ground level. The vehicle continued forward through the opening in the rail, making contact with and fracturing



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-20
Date	09/09/93
Test Article	
Type	Terminal
Name or Manufacturer	Mini-MELT
Installation Length (m)	46 (150 ft)
Size and/or Dimension and Material of Key Elements	635-762 mm (25-30 in) mount ht W-Beam (ARTBA RE-3-73) on S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Dodge Custom 250
Mass (kg) Curb	1920 (4229 lb)
Test Inertial	2000 (4405 lb)
Dummy	78 (172 lb)
Gross Static	2078 (4577 lb)

Impact Conditions	
Speed (km/h)	101.8 (63.3mi/h)
Angle (deg)	20.8
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.1 (13.3 ft/s)
y-direction	3.0 (9.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-3.6
y-direction	-4.4
PHD (optional)	
ASI (optional)	
Max. 0.050-s Averages (g's)	
x-direction	-1.7
y-direction	-2.9
z-direction	1.4

Test Article Deflections (m)	
Dynamic	2.0 (6.7 ft)
Permanent	1.7 (5.5 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ4 & 01LD2
CDC	01FREK3 & 01RDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	330 (13.0 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	90
Max. Pitch Angle (deg)	4
Max. Yaw Angle (deg)	-42

Figure 67. Summary of results for test 471470-20.

posts 6 and 7 just below ground level. The vehicle lost contact with the separated terminal end section and was traveling at a speed of 70.8 km/h (44.0 mi/h). As the vehicle continued behind the installation, it began to slide sideways as it yawed counterclockwise. The vehicle came to rest 61 m (201 ft) downstream and 21 m (70 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 68.

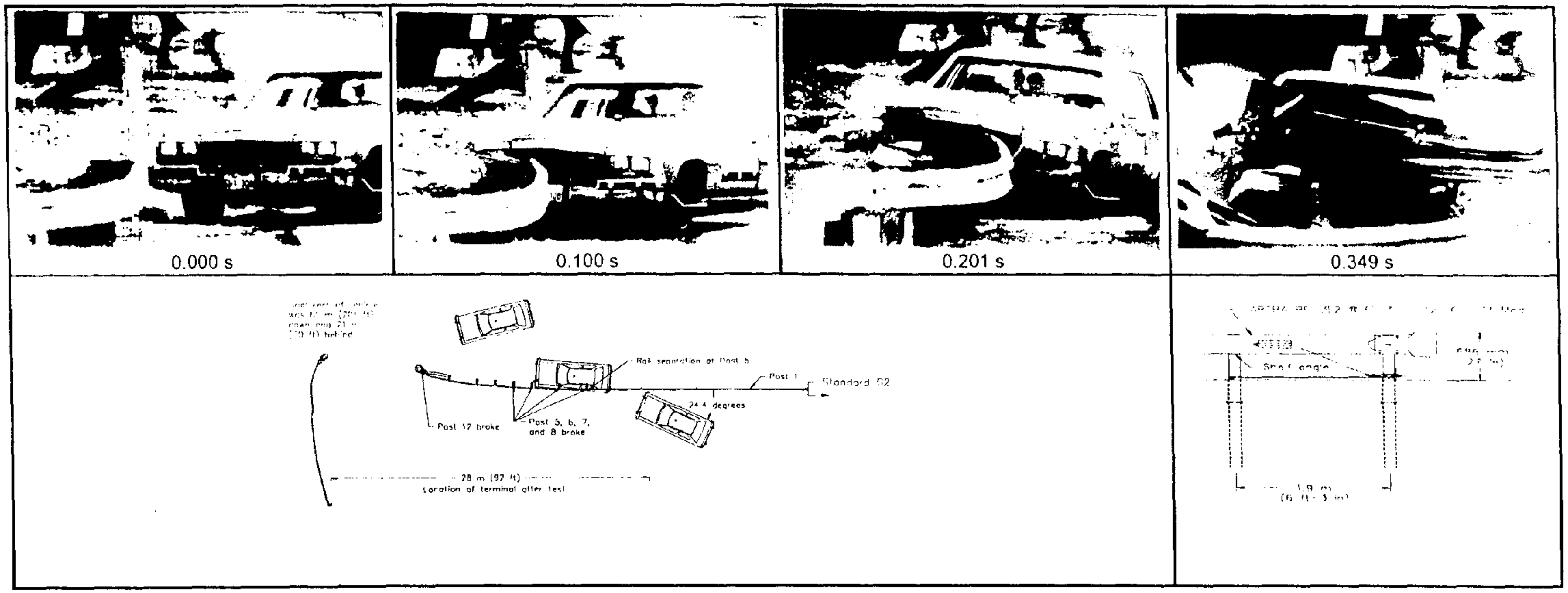
Post 1 was displaced 32 mm (2.3 in), post 2 - 127 mm (5.0 in), post 3 - 191 mm (7.5 in), and post 4 - 279 mm (11.0 in). Posts 5 through 8 were fractured below ground level and post 12 (end post) was fractured at ground level where the 60.3-mm- (2-3/8-in-) diameter hole had been drilled. Posts 9, 10, and 11 were not damaged or displaced. The W-beam rail element ruptured at the bolt holes on the underlapped element at the splice located at post 5 (last wooden post of the terminal). The maximum dynamic deflection before the rail rupture was 0.3 m (1.09 ft).

The vehicle's front stabilizer bar was bent, the windshield was cracked, and the right rear tire was aired out. The front bumper, grill, hood, fan, radiator, air conditioner compressor, and the left and right front quarter panels were also damaged. Maximum exterior crush at the right front corner of the vehicle was 300 mm (11.8 in) at bumper height. There was no intrusion or deformation of the occupant compartment.

11.4 TEST NUMBER 471470-24 (NCHRP REPORT 230 TEST DESIGNATION S31)

Test vehicle: 1982 Cadillac Coupe	Impact speed: 97.8 km/h (60.8 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.7 degrees
Gross static weight: 2118 kg (4664 lb)	

The vehicle impacted the transition area in the reverse direction (i.e., opposite to normal direction of travel) just upstream of post 13 (i.e., 4.6 m (15 ft) upstream of the last wooden post (post 8) of the Mini-MELT). As the vehicle impacted the terminal, the W-beam rail element began to deform and posts 12 and 13 began to displace laterally. The front tire of the vehicle impacted post 13 shortly afterwards, and movement began at posts 11, 14, and 10, respectively. The vehicle contacted post 12, and the right front tire aired out as it rode over post 12. Contact was made with post 11 and post 10 and the rear of the vehicle made contact with the rail near post 14. The vehicle then made contact with post 9 and post 8. The vehicle became parallel with the installation traveling at 73.2 km/h (45.5 mi/h). Maximum deflection of 0.96 m (3.15 ft) occurred near the post 10 location. The vehicle lost contact with the installation traveling at a speed of 58.4 km/h (36.3 mi/h) and at an exit angle of 8.8 degrees. As the vehicle exited the rail, it began to yaw clockwise, and subsequently came to rest 35 m (116 ft) downstream and 1.8 m (6 ft) forward of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 69.

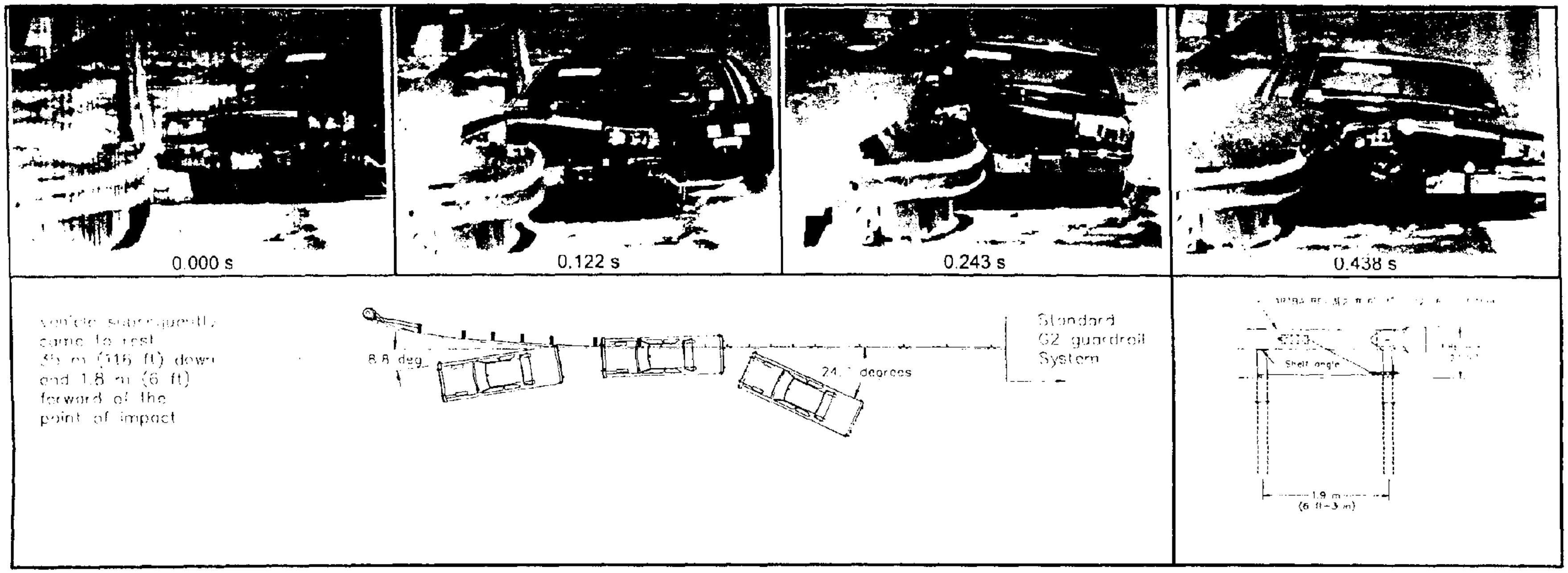


General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-23
Date	02/28/94
Test Article	
Type	Terminal
Name or Manufacturer	Modified MELT
Installation Length (m)	76 (250 ft)
Size and/or Dimension and Material of Key Elements	Modified MELT On G2 Weak-Post Guardrail System
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2043 kg (4500 lb)
Model	1984 Cadillac Fleetwood
Mass (kg) Curb	1778 (3915 lb)
Test Inertial	2043 (4500 lb)
Dummy	75 (165 lb)
Gross Static	2117 (4662 lb)

Impact Conditions	
Speed (km/h)	97.3 (60.5 mi/h)
Angle (deg)	24.4
Exit Conditions	
Speed (km/h)	70.8 (44.0 mi/h)
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.9 (19.4 ft/s)
y-direction	2.5 (8.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-8.1
y-direction	-3.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.9
y-direction	-2.7
z-direction	-3.1

Test Article Deflections (m)	
Dynamic	0.3 (1.09 ft) (Before Separation)
Permanent	Separated
Vehicle Damage	
Exterior	
VDS	12FC6
CDC	12FCEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	300 (11.8 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	20
Max. Pitch Angle (deg)	3
Max. Yaw Angle (deg)	-49

Figure 68. Summary of results for test 471470-23.



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-24
Date	03/22/94
Test Article	
Type	Terminal
Name or Manufacturer	Modified MELT
Installation Length (m)	76 (250 ft)
Size and/or Dimension and Material of Key Elements	Modified MELT On G2 Weak-Post Guardrail System
Soil Type and Condition ...	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2043 kg (4500 lb)
Model	1982 Cadillac Coupe
Mass (kg) Curb	1725 (3798 lb)
Test Inertial	2043 (4500 lb)
Dummy ...	75 (165 lb)
Gross Static	2118 (4664 lb)

Impact Conditions	
Speed (km/h)	97.8 (60.8 mi/h)
Angle (deg)	24.7
Exit Conditions	
Speed (km/h)	58.4 (36.3 mi/h)
Angle (deg)	8.8
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.3 (20.6 ft/s)
y-direction	4.8 (15.8 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-6.5
y-direction	-9.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.2
y-direction	-5.8
z-direction	2.0

Test Article Deflections (m)	
Dynamic	0.96 (3.15 ft)
Permanent	0.55 (1.80 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ3 & 01RD4
CDC	01FREK3 & 01RDEW2
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm) ..	350 (13.8 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg) ...	-11
Max. Pitch Angle (deg) ..	3
Max. Yaw Angle (deg) ...	-31

Figure 69. Summary of results for test 471470-24.

The bolts were pulled out of the W-beam rail element at posts 10 and 12. None of the posts broke off, but some posts were pushed back. The W-beam rail element sustained some local deformation at post 8 (the first wood post) and there was evidence of tire contract with post 8. Maximum dynamic deflection of the guardrail during the test was 0.96 m (3.15 ft) at post 10. Maximum permanent deformation of the guardrail was 0.55 m (1.80 ft), also at post 10. The vehicle was in contact with the guardrail system for a total length of 9.6 m (31.5 ft).

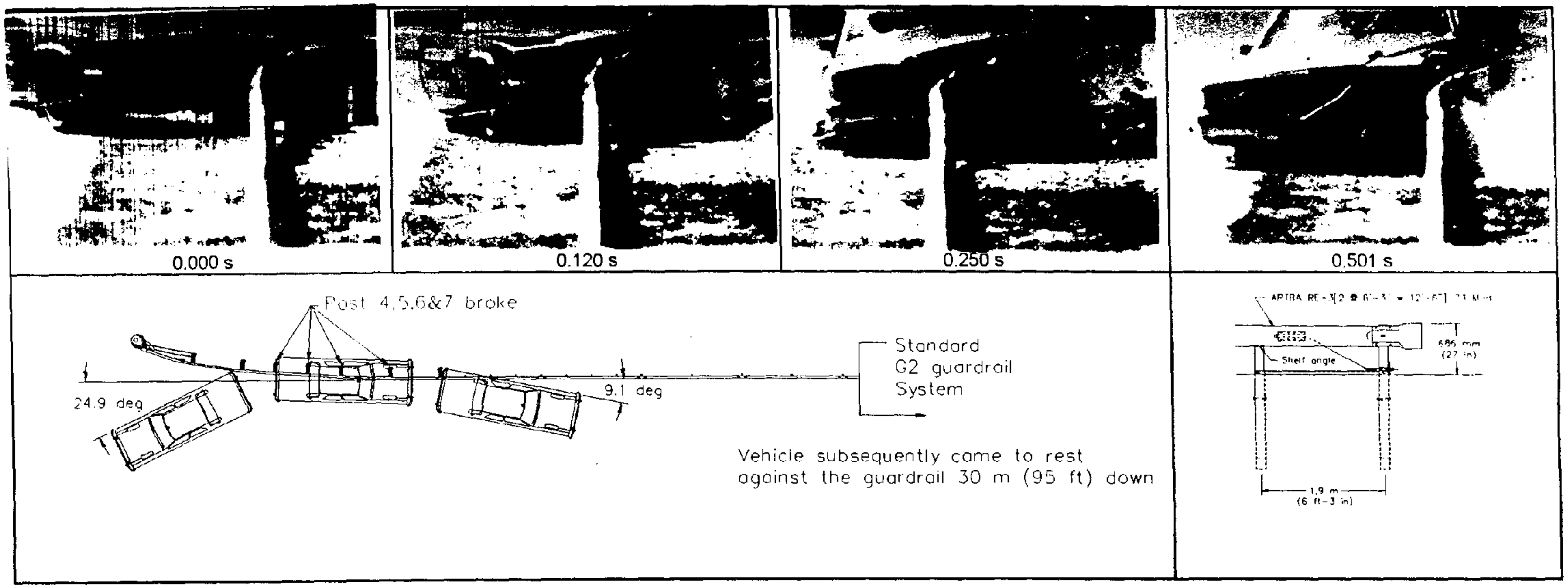
The drive shaft was bent, the lower right A-arm was damaged, and the right rear axle mount broke on the vehicle. The right front and rear tires were aired out and the rims were bent. The front bumper, grill, hood, the left and right front quarter panels, the right door, the right rear quarter panel, and the rear bumper were also damaged. Maximum exterior crush at the right front corner of the vehicle was 350 mm (13.8 in) at bumper height. There was no intrusion or deformation of the occupant compartment.

11.5 TEST NUMBER 471470-25 (NCHRP REPORT 230 TEST DESIGNATION 40)

Test vehicle: 1986 Cadillac Sedan	Impact speed: 97.8 km/h (60.8 mi/h)
Test inertia weight: 2043 kg (4500 lb)	Impact angle: 24.9 degrees
Gross static weight: 2119 kg (4666 lb)	

The vehicle impacted the terminal just upstream of post 3 (i.e., at the beginning of length of need) or 3.8 m (12 ft, 6 in) downstream of the end post. As the vehicle impacted the terminal, the W-beam rail element began to deform and post 4 began to displace laterally. The front tire of the vehicle impacted post 3 and the W-beam element began to displace forward at post 5. The vehicle began to redirect and made contact with post 4. The W-beam began to pull back to post 5, and then to bend near post 6. Post 4 fractured at ground level, post 5 fractured and the vehicle rode over it. Post 6 fractured, the vehicle impacted the post, and the rear of the vehicle made contact with the W-beam element. The front of the vehicle contacted post 7, fracturing the post, and at the same time, the vehicle became parallel with the installation traveling at 75.3 km/h (46.8 mi/h). Maximum dynamic deflection of 1.2 m (3.8 ft) occurred between the post 6 and 7 locations. The front tire contacted post 9 and the tire aired out. The vehicle lost contact with the installation traveling at 52.3 km/h (32.5 mi/h) and at an exit angle of 9.1 degrees. As the vehicle exited the rail, it began to yaw counterclockwise, subsequently impacting the guardrail 27 m (89 ft) downstream of the point of initial impact. The vehicle rode along the guardrail for 1.9 m (6.3 ft) and stopped against the guardrail. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 70.

Posts 4 through 7 broke off near ground level, and the blockout on post 8 was splintered. A number of other posts were pushed back. For posts 4 through 7 that broke off, the post displacement measurements indicate maximum post movement just prior to breaking of the posts. The W-beam rail element was buckled and torn (but not ruptured) at the lower splice bolts on the outer edge of the splice located at post 8. The tearing propagated over half the width of the W-beam rail element, indicating that the tensile capacity of the W-beam rail



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-25
Date	03/31/94
Test Article	
Type	Terminal
Name or Manufacturer	Modified MELT
Installation Length (m)	76 (250 ft)
Size and/or Dimension and Material of Key Elements	Modified MELT On G2 Weak-Post Guardrail System
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2043 kg (4500 lb)
Model	1986 Cadillac Sedan
Mass (kg) Curb	1727 (3803 lb)
Test Inertial	2043 (4500 lb)
Dummy	75 (165 lb)
Gross Static	2119 (4666 lb)

Impact Conditions	
Speed (km/h)	97.8 (60.8 mi/h)
Angle (deg)	24.9
Exit Conditions	
Speed (km/h)	58.4 (36.3 mi/h)
Angle (deg)	9.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.0 (19.7 ft/s)
y-direction	4.6 (15.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-5.7
y-direction	-6.8
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.8
y-direction	5.6
z-direction	-2.1

Test Article Deflections (m)	
Dynamic	1.2 (3.8 ft)
Permanent	0.8 (2.5 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ5 & 11LD5
CDC	11FYEK3 & 11LDEW3
Interior	
OCDI	FS0000000
Maximum Exterior Vehicle Crush (mm)	380 (15.0 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	9
Max. Pitch Angle (deg)	5
Max. Yaw Angle (deg)	36

Figure 70. Summary of results for test 471470-25.

element was reached. Maximum dynamic deflection of the W-beam during the test was 1.2 m (3.8 ft) between posts 6 and 7. Maximum permanent deformation of the W-beam was 0.8 m (2.5 ft) at the post 6 location. The vehicle was in contact with the terminal for a total length of 8.9 m (29.2 ft).

The vehicle's outer tire rod and lower A-arm on the left side, and the sway bar were damaged. The right front and rear tires were aired out and the rims were bent. The front bumper, grill, hood, the left and right front quarter panels, the left door, the left rear quarter panel, and the rear bumper also were damaged. Maximum exterior crush at the left front corner of the vehicle was 380 mm (15.0 in) at bumper height. There was no intrusion or deformation of the occupant compartment.

11.6 SUMMARY OF FINDINGS

In the first crash test (test no. 471470-20) with the initial design, the mini-MELT successfully contained and redirected the vehicle. Post 5 fractured during the test sequence, but exhibited no undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. However, as the vehicle was being redirected past the point where the vehicle was parallel with the installation, the vehicle began to roll clockwise. The clockwise roll continued as the vehicle separated from the guardrail. The vehicle eventually rolled 90 degrees onto its right side and then righted itself upon contact with the pavement. The trajectory of the vehicle was judged to pose a minimal hazard to adjacent traffic as the vehicle was traveling almost parallel to the installation after separation and subsequently came to rest 9 m (31 ft) behind the point of impact. The occupant risk factors were all well within the desirable limits set forth in NCHRP 350, as shown in table 28. The impact performance of the mini-Melt was considered unsatisfactory in this test because of the rollover.

In the second crash test (test no. 471470-23) on the transition section between the G2 guardrail system and the modified mini-MELT, the guardrail failed to contain or redirect the impacting vehicle in this reverse-direction test. The W-beam rail element ruptured at the last wooden post of the terminal section (post 5), allowing the vehicle to penetrate and travel behind the test installation. The end post was fractured and the separated end terminal section was thrown forward during the test sequence, which could potentially pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during the initial collision period. The trajectory of the vehicle was judged to have posed a minimal hazard to adjacent traffic as the vehicle penetrated and came to rest behind the guardrail. Although not required as part of the evaluation criteria for this test, the occupant risk factors were all well within the desirable limits set forth in NCHRP Report 230. In summary, the transition section between the Mini-MELT and the standard G2 guardrail system failed to contain and redirect the test vehicle and was judged to have failed the evaluation criteria set forth in NCHRP Report 230, as summarized in table 29.

Table 28. Assessment of results of test 471470-20 (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute — Test No.: 471470-20 — Test Date: 09/09/93

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The Mini-MELT contained and redirected the vehicle. A maximum dynamic deflection of 2.0 m (6.7 ft) was attained with a residual deformation of 1.7 m (5.5 ft).	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Post 5 fractured at ground level as the vehicle's front wheel rode over it; however, it remained where it separated and did not exhibit any hazard to occupants, adjacent traffic, or others in the area. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle rolled 90 degrees onto its right side as the vehicle was being redirected. The vehicle then righted itself upon contact with the pavement.	Fail
<u>Vehicle Trajectory</u>		
K. After collision it is preferable that the vehicle's trajectory does not intrude into adjacent traffic lanes.	Vehicle intrusion into adjacent traffic lanes was judged as minimal.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.1 m/s Longitudinal Ridedown Acceleration = -3.6 g's	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle was out of view from the overhead camera and airborne as it lost contact with the installation; however, it was traveling almost parallel with the installation.	Pass

Table 29. Assessment of results of test 471470-23 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute — Test No.: 471470-23 — Test Date: 02/28/94

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 transition section between the Mini-MELT and the G2 guardrail system failed to contain or redirect the impacting vehicle. The W-beam rail element was ruptured at a splice, allowing the vehicle to penetrate and travel behind the test installation.	Fail
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 hazards to other traffic.	A section of the Mini-MELT was detached from the test installation and was thrown forward, thereby presenting potential hazards to adjacent traffic.	Fail
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.	The vehicle remained upright and relatively stable during the initial collision period. There was no penetration or intrusion into the passenger compartment.	Pass
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Not applicable. The vehicle penetrated the installation and came to rest behind the test installation.	N/A
I. In a test 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 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.	Not applicable. The vehicle penetrated the installation and came to rest behind the test installation.	N/A

The third crash test (test no. 471470-24) was a repeat of the second crash test on a redesigned mini-MELT. The vehicle was successfully contained and smoothly redirected in this test. The maximum dynamic deflection of the guardrail was 0.96 m (3.15 ft). There were no detached elements or debris to exhibit undue hazards to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed a minimal hazard to adjacent traffic as the vehicle came to rest 1.8 m (6 ft) forward of the installation. Although not required as part of the evaluation criteria for this test, the occupant risk factors were well within the desirable limits set forth in NCHRP Report 230. The modified Mini-MELT was judged to have performed satisfactorily in this transition test.

The modified mini-MELT was then evaluated on the adequacy or strength of the anchorage in the fourth crash test (test no. 471470-25). The terminal successfully contained and smoothly redirected the impacting vehicle. The maximum dynamic deflection of the guardrail was 1.2 m (3.8 ft). The W-beam rail element was buckled and partially torn (but not ruptured) at the lower splice bolts on the outer edge of the splice located at the last wooden post (post 8). Some posts broke off and came to rest behind the test installation, but did not exhibit undue hazards to adjacent traffic or show potential for penetration of the occupant compartment. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed no potential hazard to adjacent traffic as the vehicle came to rest against the installation. Although not required as part of the evaluation criteria for this test, the occupant risk factors were well within the desirable limits set forth in NCHRP Report 230. The modified mini-MELT was judged to have performed satisfactorily in this length-of-need strength test.

In summary, the impact performance of the modified mini-MELT in the third and fourth crash tests was considered acceptable according to guidelines set forth in NCHRP Report 230, as shown in tables 30 and 31. However, it appeared that the system was performing at or near its performance limit as evidenced by the partial tearing (more than 50 percent) of the W-beam rail element in the length-of-need strength test. The W-beam rail element could easily have been torn completely and allowed the vehicle to penetrate the barrier had the impact conditions been slightly more severe.

Table 30. Assessment of results of test 471470-24 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute | Test No.: 471470-24 | Test Date: 03/22/94

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 modified Mini-MELT contained and redirected the impacting vehicle. The vehicle did not penetrate or go over the installation.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present an undue hazard to other traffic.	There were no detached elements or other debris to present a hazard to occupants or 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.	The vehicle remained upright and relatively stable during the initial collision period. There was no penetration or intrusion into the passenger compartment.	Pass
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 intrusion into adjacent traffic lanes was judged as minimal as the vehicle came to rest 1.8 m (6 ft) forward of the installation.	Pass
I. In a test 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 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 a test device.	The change in speed of the vehicle at loss of contact was 12.2 km/h (7.6 mi/h). The exit angle was less than 60 percent of the impact angle.	Pass

Table 31. Assessment of results of test 471470-25 (according to NCHRP Report 230).

Test Agency: Texas Transportation Institute — Test No.: 471470-25 — Test Date: 03/31/94

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 modified Mini-MELT contained and redirected the impacting vehicle. The vehicle did not penetrate or go over the installation. There was, however, some buckling and partial tearing of the W-beam rail element at the lower splice on post 5.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present an undue hazard to other traffic.	There was no penetration of the occupant compartment. Some posts broke off and were thrown behind the installation, exhibiting no potential hazard to adjacent 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.	The vehicle remained upright and relatively stable during the initial collision period. There was no penetration or intrusion into the passenger compartment.	Pass
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	The vehicle came to rest against the installation and did not intrude into adjacent traffic lanes.	Pass
I. In a test 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 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 a test device.	Not applicable.	N/A

XII. EXISTING GUARDRAIL SYSTEMS

The FHWA has formally adopted the new performance evaluation guidelines for highway features set forth in NCHRP Report 350 as a "Guide or Reference" document in *Federal Register*, Volume 58, Number 135, dated July 16, 1993, which added paragraph (a)(13) to 23 CFR, Part 625.5. FHWA has also mandated that, starting in September of 1998, only highway safety appurtenances that have successfully met the performance evaluation guidelines set forth in NCHRP Report 350 may be used on the National Highway System (NHS) for new installations. Most of the existing highway features were tested according to the previous guidelines contained in NCHRP Report 230. It is, therefore, necessary to crash test and evaluate the performance of existing highway features under the newer guidelines.

One of the key revisions in the guidelines set forth in NCHRP Report 350 from those in NCHRP Report 230 is the replacement of the 2041-kg (4500-lb) passenger car by a 2000-kg (4409-lb) pickup truck as one of the design test vehicles. Very little information was available on the performance of existing highway features with the new 2000P test vehicle (i.e., 2000-kg (4409-lb) pickup truck). As part of an effort by FHWA to evaluate the performance of existing highway features with the new 2000P test vehicle, a series of crash tests with the new 2000P test vehicle were conducted on various existing guardrail systems, including:

- Cable (G1) guardrail system,
- W-beam, weak-post (G2) guardrail system,
- Box-beam (G3) guardrail system,
- W-beam, strong-post (G4) guardrail system,
- Thrie-beam (G9) guardrail system, and
- Modified thrie-beam guardrail system.

This chapter presents the results of crash tests on these existing guardrail systems. Testing and evaluation was performed according to guidelines outlined in NCHRP Report 350.

12.1 TEST INSTALLATIONS

12.1.1 Cable (G1) Guardrail System

The cable (G1) guardrail system consisted of three 191-mm- (3/4-in-) diameter round wire cable mounted on S3x5.7 steel posts, spaced 4.9 m (16 ft) on center, a cross-section of which is shown in figure 71. The 19.1-mm- (3/4-in-) diameter round wire cable consisted of three strands (seven wires per strand) with a minimum tensile strength of 115.7 kN (26,000 lb). The mounting heights for the center of the three cables were 597, 673, and 749 mm (23.5, 26.5, and 29.5 in), respectively. The cables were attached to the posts with 7.9-mm (5/16-in) diameter hook bolts. The S3x5.7 steel posts were 1.6 m (63 in) long with

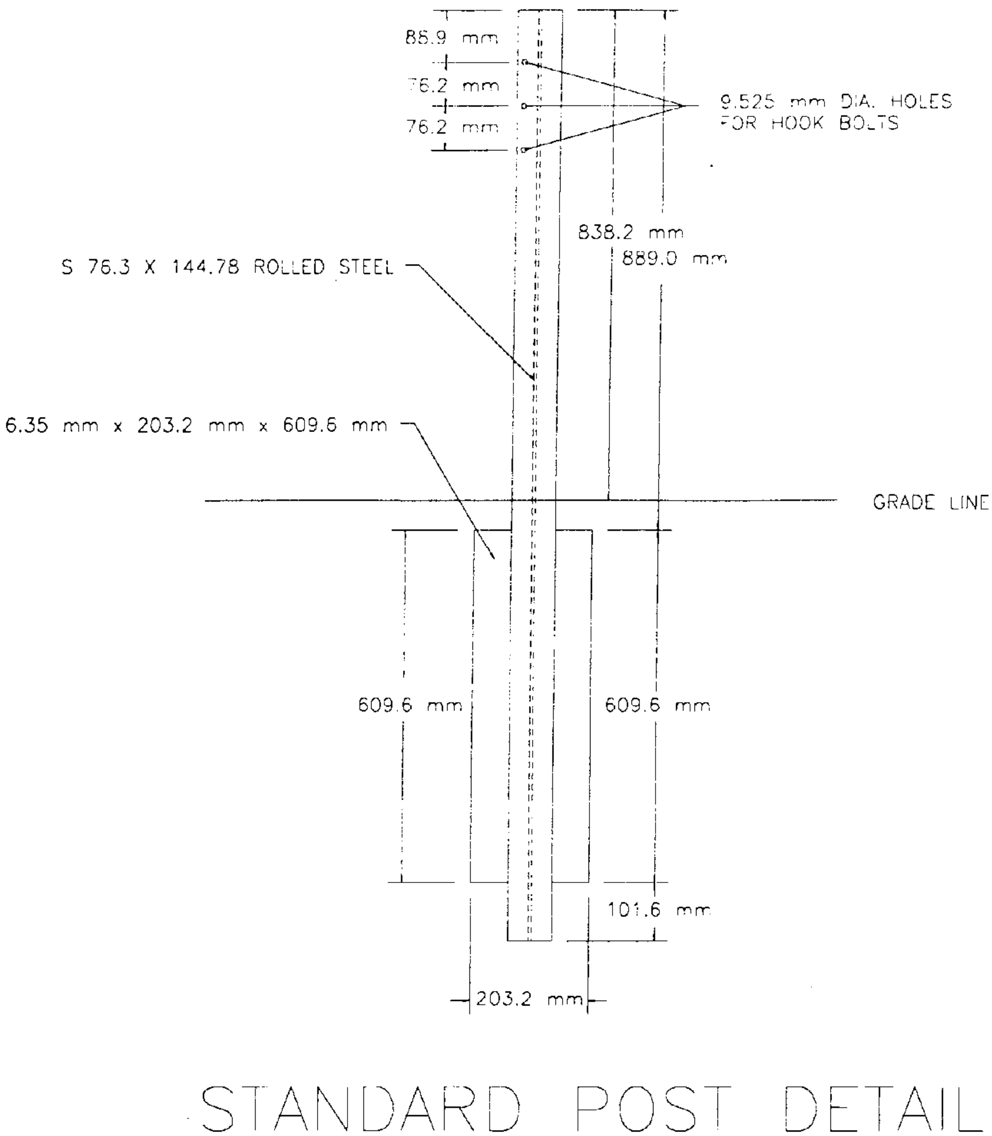


Figure 71. Cross-section of the cable (G1) guardrail system.

an embedment depth of 762 mm (30 in). A 203-mm × 610-mm × 6.4-mm (8-in × 24-in × 1/4-in) soil plate was used with the steel posts.

The 12.8-m- (42-ft-) long terminal section consisted of a 7.3-m- (24-ft) section with four S3x5.7 posts spaced at 1.83 m (6.0 ft) and the last 5.5 m (18 ft) was unsupported (i.e., the first or end post was located 5.5 m (18 ft) from the concrete anchor). The full guardrail height of 762 mm (30 in) was maintained until the second post where the cables began to slope down to ground level at the concrete anchor. The first two posts had end caps with shelf angles for the cables instead of the hook bolts. The first or end post was also mounted at a reduced height to accommodate the sloping of the cables. The cables were anchored to a concrete block with a breakaway anchor angle, details of which are shown in figure 72.

12.1.2 W-Beam, Weak-Post (G2) Guardrail System

The W-beam, weak-post (G2) guardrail system consisted of 1.6-m- (5-ft, 3-in-) long S3x5.7 posts with 203-mm × 610-mm × 6.4-mm (8-in × 24-in × 1/4-in) soil plates, spaced 3.8 m (12 ft, 6 in) center to center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. A cross-section of the W-beam, weak-post (G2) guardrail system is shown in figure 73. The height of the guardrail to the top of the W-beam rail element was 0.76 m (30 in). The W-beam rail elements were attached to the posts with 7.94-mm- (5/16-in-) diameter bolts and square plate washers. Also, 12.7-mm- (1/2-in-) diameter and 38.1-mm- (1-1/2-in-) long shelf bolts were attached to the posts with two or more nuts for the W-beam rail elements to rest on. The purpose of the shelf bolts is to reduce the loading on the 7.94-mm- (5/16-in-) diameter post bolts from the weight of the W-beam rail elements and other dead load, such as snow and ice on the rail elements.

12.1.3 Box-Beam (G3) Guardrail System

The box-beam (G3) guardrail system consisted of 1.6-m- (5-ft, 4-in-) long S3x5.7 steel posts spaced 1.8 m (6 ft) apart, a cross-section of which is shown in figure 74. A L127 mm × 89 mm × 10 mm × 114 mm long (L5 in × 3-1/2 in × 3/8 in × 4-1/2 in long) shelf angle was attached to the post with a 13-mm- (1/2-in-) diameter, 38-mm- (1-1/2-in-) long hex bolt with washer and nut. A TS 152-mm × 152-mm × 4.8-mm tubular steel (TS 6-n × 6-in × 3/16-in) box-beam rail element was attached to the support angle with a 10-mm- (3/8-in-) diameter, 191-mm- (7-1/2-in-) long hex bolt with washer and nut. The mounting height of the box beam rail was 686 mm (27 in) to the top of the box-beam rail element.

12.1.4 W-beam, Strong-Post (G4) Guardrail Systems

Both W-beam, strong-post guardrail systems, one with wooden posts and blockouts, G4(2W), and the other with steel posts and blockouts, G4(1S), were crash tested.

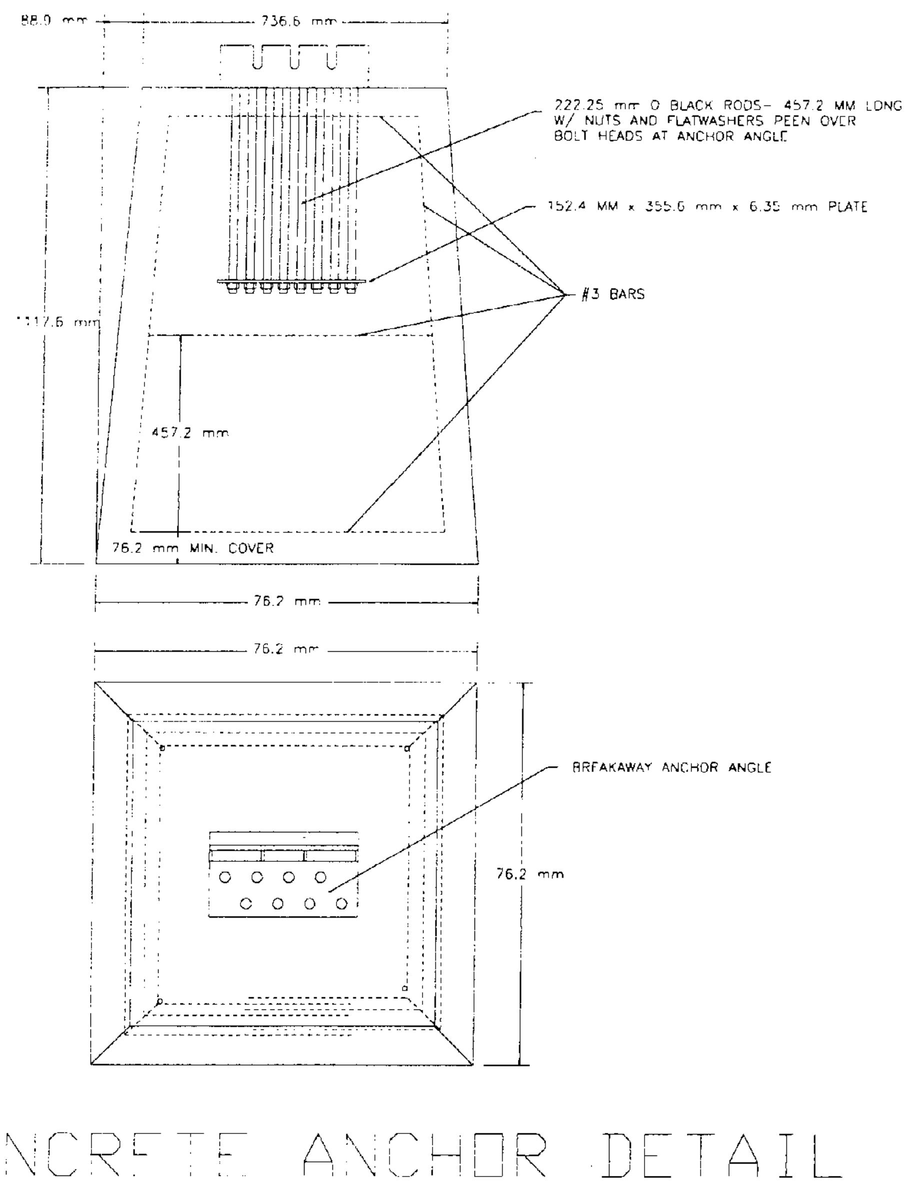


Figure 72. Details of breakaway anchor for cable (G1) guardrail system.

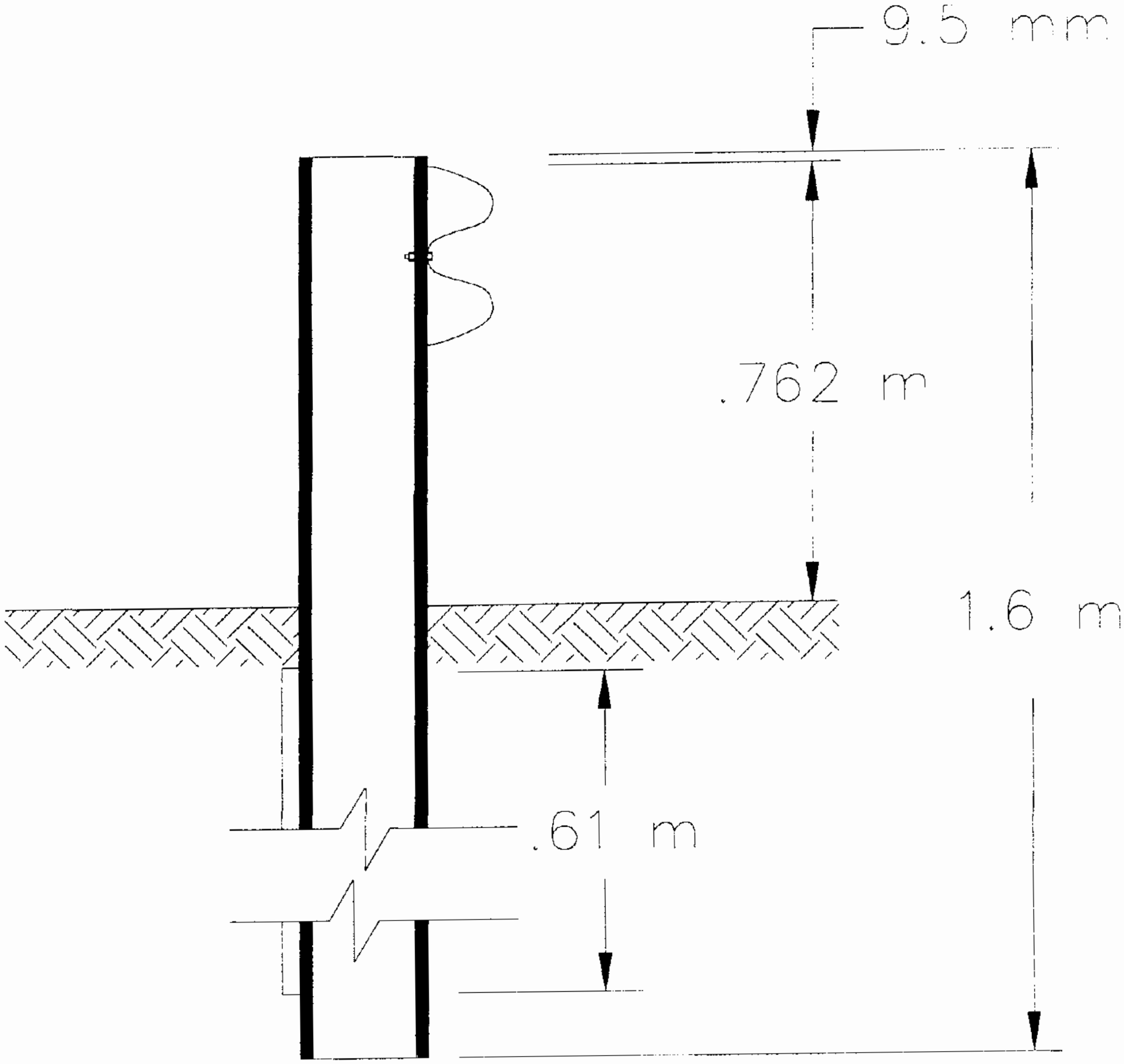


Figure 73. Cross-section of W-beam, weak-post (G2) guardrail system.

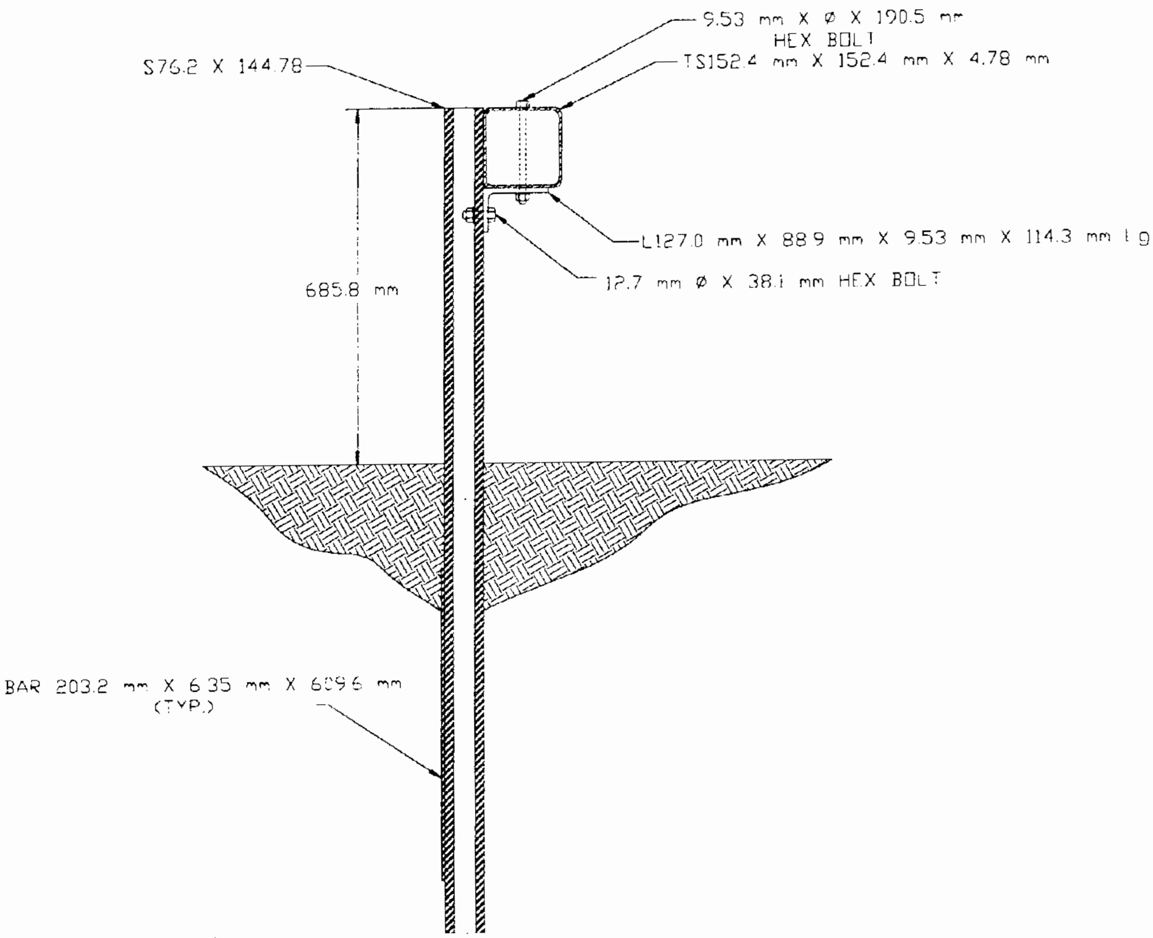


Figure 74. Cross-section of the box-beam (G3) guardrail system.

As shown in figure 75, the G4(2W) guardrail system consisted of 1.6-m- (5-ft, 4-in-) long, 152-mm × 203-mm (6-in × 8-in) wood posts with 356-mm- (14-in-) long, 152-mm × 203-mm (6-in × 8-in) wooden blockouts, spaced 1.9 m (6 ft, 3 in) on center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers.

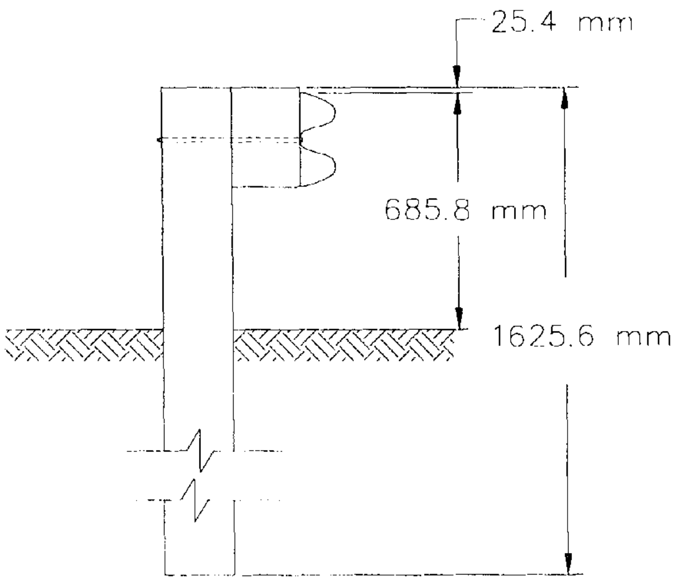
The G4(1S) guardrail system consisted of 1.8-m- (6-ft, 0-in-) long, W6x9 steel posts with 356-mm- (14-in-) long W6x9 steel blockouts, spaced 1.9 m (6 ft, 3 in) on center, and 3.8-m- (12-ft, 6-in-) long 12-gauge W-beam rail elements. A cross-section of the G4(1S) guardrail system is shown in figure 76. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers. Backup plates, similar in cross section to the W-beam rail element and 305 mm (12 in) in length, were used at non-splice posts.

12.1.5 Thrie-Beam (G9) Guardrail System

As shown in figure 77, the thrie-beam (G9) guardrail system consisted of 2.0-m (6-ft, 6-in-) long W6x9 steel posts spaced 1.9 m (6 ft, 3 in) apart with 546-mm- (21.5-in-) long W6x9 steel blockouts. The blockout was attached to the post with two 15.9-mm- (5/8-in-) diameter bolts and the thrie-beam rail element was attached to the blockout with two 15.9-mm- (5/8-in-) diameter button head bolts without washers. The mounting height of the thrie-beam rail was 559 mm (22 in) to the center and 813 mm (32 in) to the top of the thrie-beam rail element.

12.1.6 Modified Thrie-Beam Guardrail System

The modified thrie-beam guardrail system consisted of 2.1-m- (6-ft, 9-1/4-in) long W6x9 steel posts spaced 1.9 m (6 ft, 3 in) apart with M14x18 blockouts. A cross-section of the modified thrie-beam guardrail system is shown in figure 78. The blockouts were 432 mm (17 in) long, 457 mm (18 in) deep, and 152 mm (6 in) wide at the flanges. The webbing of the blockout had a cutout measuring 152 mm (6 in) at the bottom and angled upward at 40 degrees to the flange upon which the thrie-beam was attached. The blockout was attached to the post with four 15.9-mm- (5/8-in-) diameter bolts and the thrie-beam rail element was attached to the blockout with a single 15.9-mm- (5/8-in-) diameter button head bolt without a washer. The mounting height of the thrie-beam rail was 610 mm (24 in) to the center and 864 mm (34 in) to the top of the thrie-beam rail element.



G4(2W)

Post Type:	152x203 Wood
Post Spacing:	1.9 m
Beam Type:	12-gauge W-beam
Blockout:	152x203x356 Wood
Mountings:	16 mm dia. carriage bolts

Figure 75. Cross-Section of the W-beam, wood-post (G4(2W)) guardrail system.

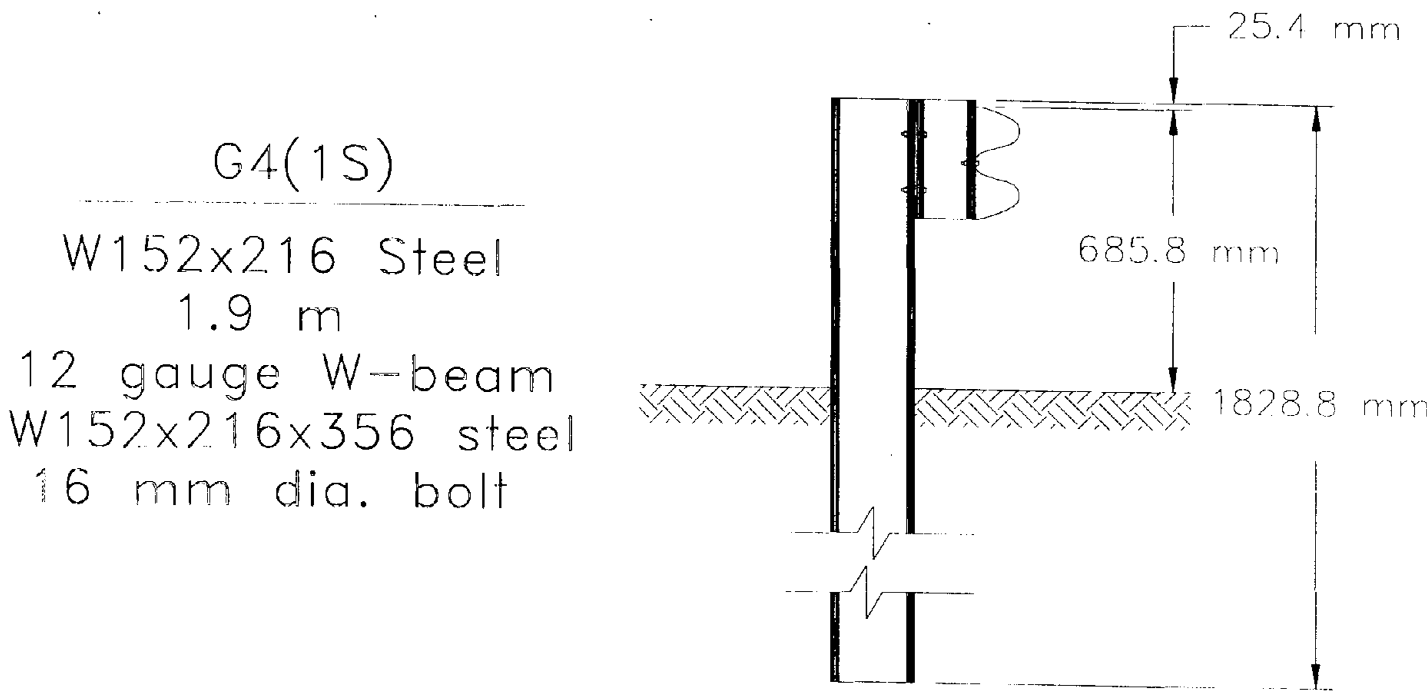


Figure 76. Cross-section of the W-beam, steel-post (G4(1S)) guardrail system.

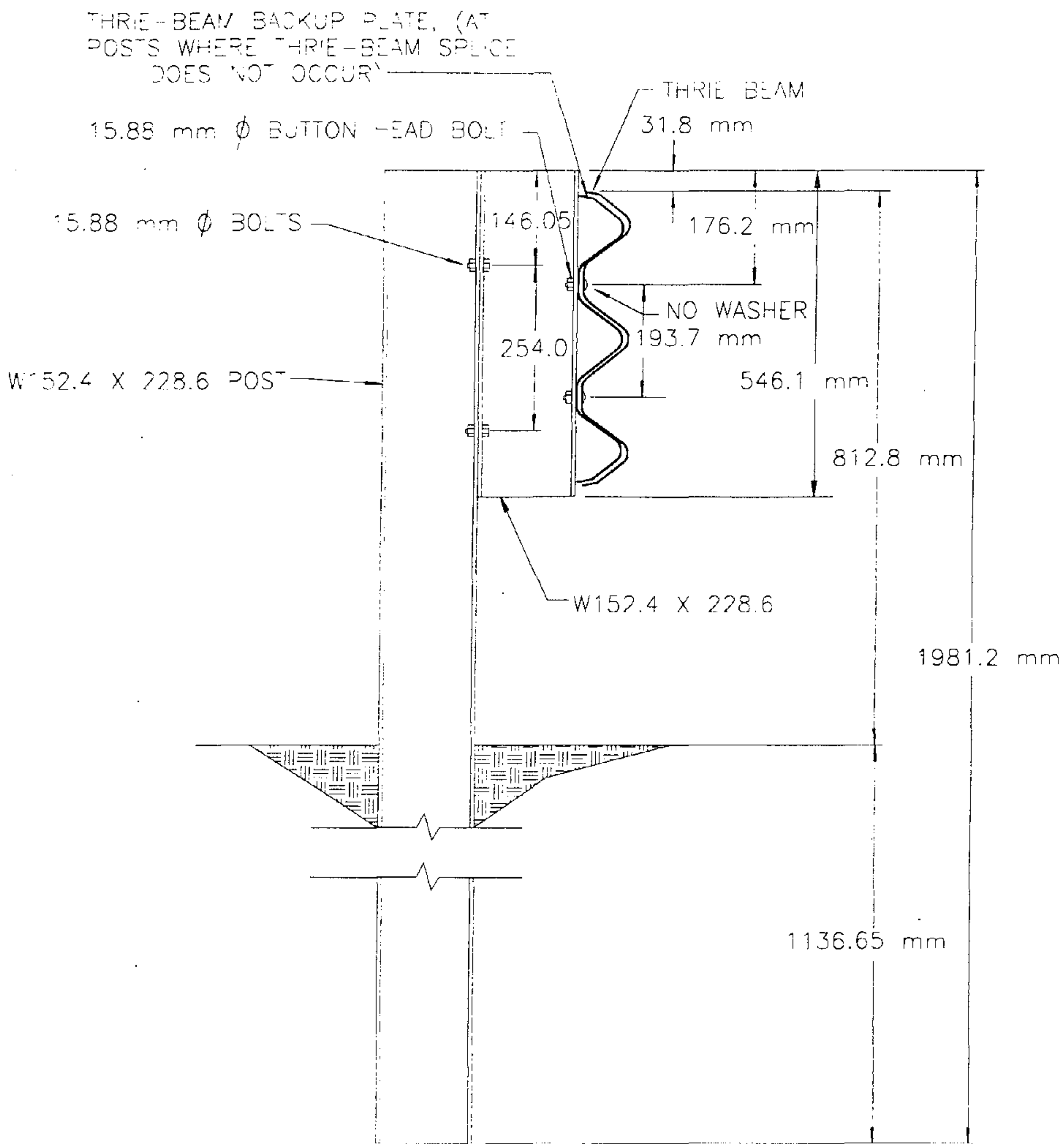


Figure 77. Cross-section of the thrie-beam (G9) guardrail system.

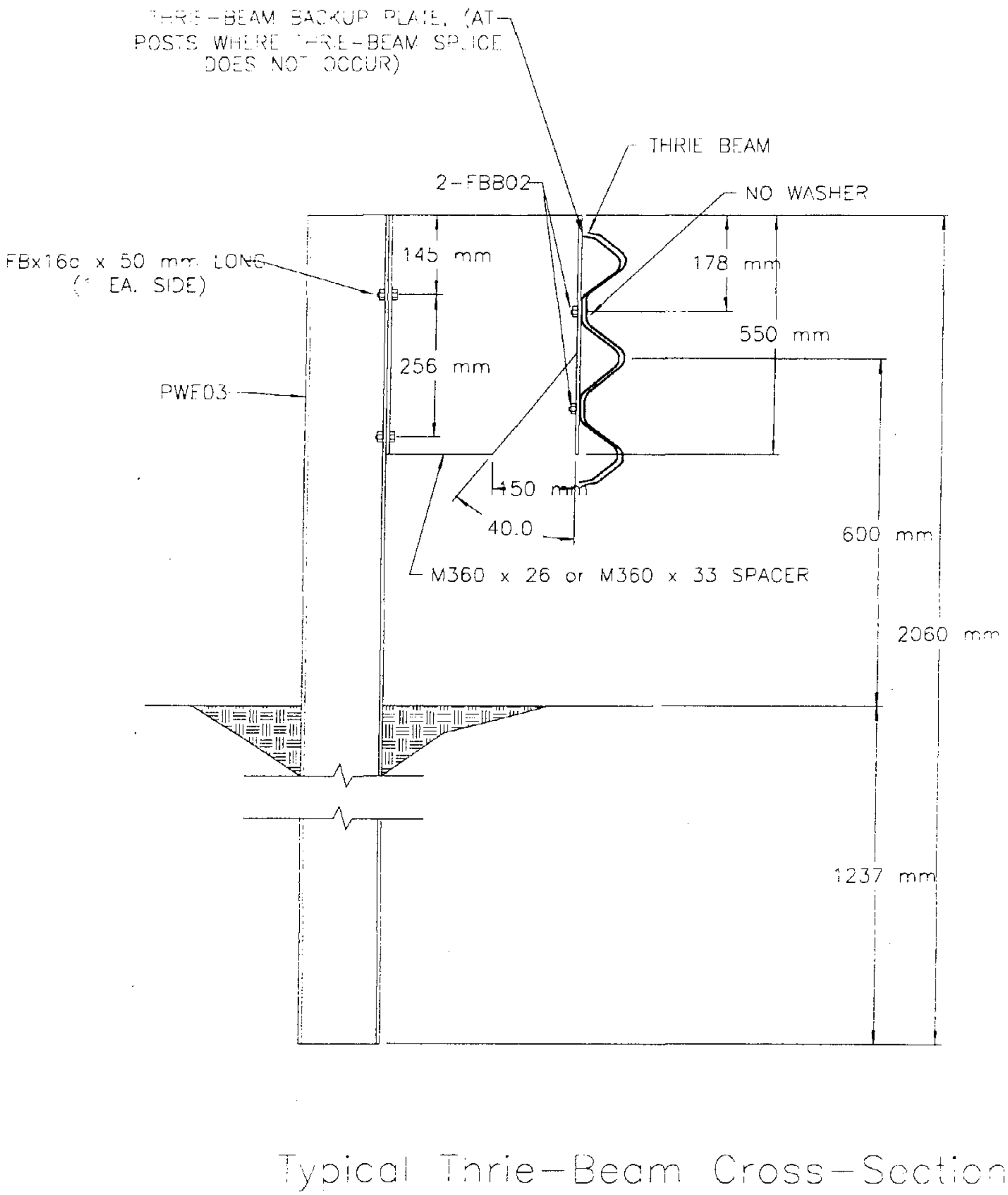


Figure 78. Cross-section of the modified thrie-beam guardrail system.

12.2 CABLE (G1) GUARDRAIL SYSTEM
Test Number 471470-28 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 Chevrolet 2500 Pickup Test inertia weight: 2000 kg (4409 lb) Gross static weight: 2075 kg (4570 lb)	Impact speed: 95.1 km/h (59.1 mi/h) Impact angle: 26.7 degrees

The test installation consisted of a 92.7-m- (304-ft-) long section of the cable (G1) guardrail system with a 12.8-m- (42-ft-) long terminal at each end, for a total installation length of 118.3 m (388 ft). The vehicle impacted the length-of-need section midway between posts 10 and 11. As the vehicle impacted the installation, the cables began to deflect and the posts on either side of the impact point began to move inward and back. Redirection of the vehicle began and vehicle contact with post 11 occurred. Post 12 began to move rearward and began to pull out of the ground. The front of the vehicle contacted post 12 and the cables made contact with the entire side of the vehicle. Post 13 began to pull out of the ground. The vehicle became parallel with the installation traveling at 77.3 km/h (48.0 mi/h). Maximum deflection of the cables was 2.4 m (7.8 ft). The vehicle contacted posts 13 and 14 and then lost contact with the installation traveling at 60.3 km/h (37.5 mi/h) and at an exit angle of approximately 2.0 degrees. The vehicle brakes were applied after the vehicle exited the test area, and it subsequently came to rest 97 m (318 ft) down and 7 m (24 ft) forward of the impact point. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 79.

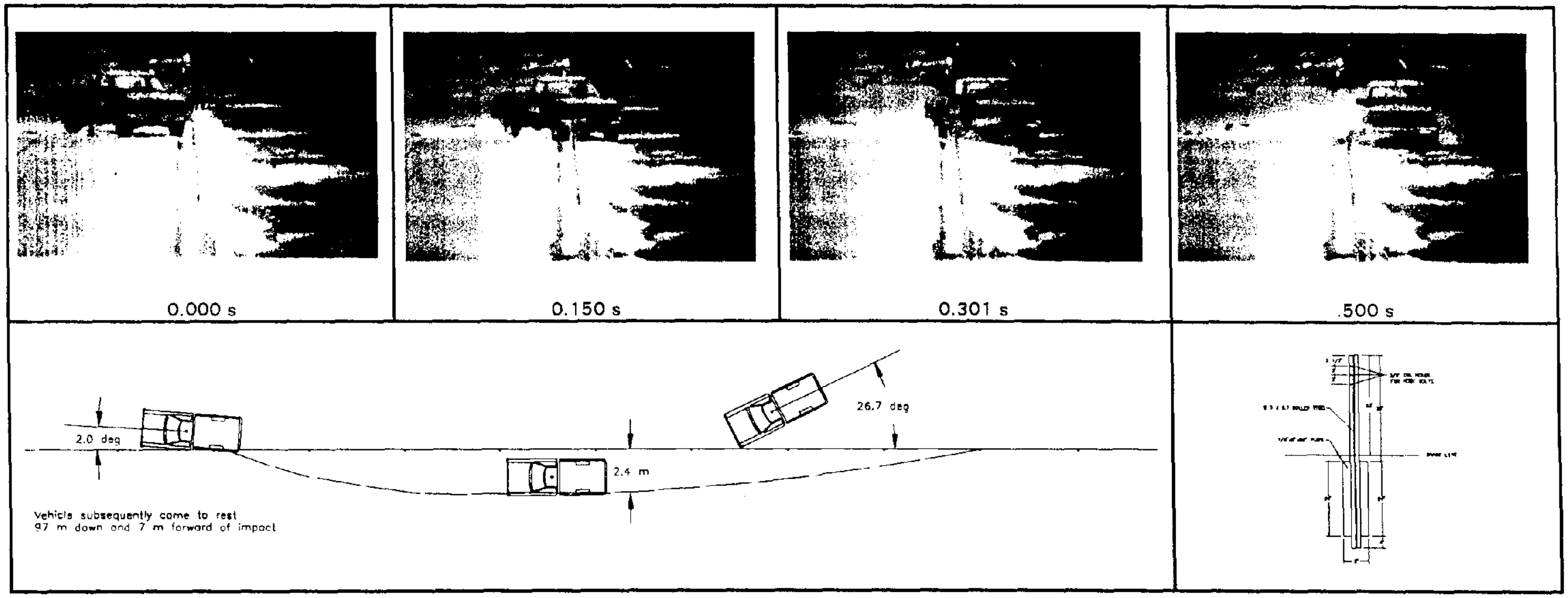
The cables were separated from the posts between posts 10 through 16. Posts 8 through 16 were pushed back or pulled out of the ground. Maximum dynamic deflection of the cables during the test was 2.4 m (7.8 ft). Maximum permanent deformation of the installation was 0.3 m (0.9 ft). The upstream concrete anchor was pulled up 89 mm (3.5 in) and inward 95 mm (3.8 in). The downstream anchor was pulled up and inward 57 mm (2.3 in).

The front bumper and grill were damaged, and the entire left side of the vehicle was scraped by the wire rope. Maximum exterior crush at the left front corner of the vehicle was 360 mm (14.2 in) and there was no deformation or intrusion into the occupant compartment.

12.3 W-BEAM, WEAK-POST (G2) GUARDRAIL SYSTEM
Test Number 471470-21 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1985 Chevrolet Pickup Test inertia weight: 2000 kg (4409 lb) Gross static weight: 2076 kg (4573 lb)	Impact speed: 99.8 km/h (62.0 mi/h) Impact angle: 24.4 degrees

The test installation consisted of 45.7 m (150 ft) of length-of-need section with a 7.62-m- (25-ft-) long turned-down terminal at each of the two ends, for a total installation length of 61.0 m (200 ft). The vehicle impacted the terminal system at midspan between



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-28
Date	11/15/94
Test Article	
Type	Guardrail
Name or Manufacturer	G1 Wire Rope
Installation Length (m)	122 m (400 ft)
Size and/or Dimension and Material of Key Elements	3/4-in Round Wire Cable on S3x5.7 Steel Posts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1774 (3907 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2075 (4570 lb)

Impact Conditions	
Speed (km/h)	95.1 (59.1 mi/h)
Angle (deg)	26.7
Exit Conditions	
Speed (km/h)	60.3 (37.5 mi/h)
Angle (deg)	2.0
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.3 (14.2 ft/s)
y-direction	3.5 (11.6 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.0
y-direction	5.6
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-2.0
y-direction	2.9
z-direction	1.9

Test Article Deflections (m)	
Dynamic	2.4 (7.8 ft)
Permanent	0.3 (0.9 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ3
CDC	11FYEK1 & 11LDEW2
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	360 (14.2 in)
Max. Occ. Compart. Deformation (mm)	0 (0 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	10
Max. Pitch Angle (deg)	-3
Max. Yaw Angle (deg)	27

Figure 79. Summary of results for test 417470-28.

posts 5 and 6. As the vehicle impacted the guardrail installation, the W-beam rail element began to deform and post 6 and 5 began to deflect. Post 7 (second post downstream from impact) began to deflect and the vehicle began to redirect. As the vehicle continued forward, the W-beam rail element rode over the top of the posts as the W-beam deformed along the path of the vehicle. The rear of the vehicle contacted the guardrail while the vehicle was traveling parallel to the installation at 80.2 km/h (49.9 mi/h). Maximum dynamic deflection of the guardrail was 2.4 m (7.9 ft). As the vehicle was being redirected, the W-beam rail element dropped and began to dig into the ground. The left front tire began to mount the guardrail and was on top of the rail. The right front wheel came into contact with the guardrail and the left rear tire came into contact with and eventually mounted the rail. The right front wheel was on top of the rail and aired out. The W-beam rail element separated from the last post, the right front tire contacted the ground, and the vehicle separated from the guardrail. The vehicle remained upright and came to rest 28.8 m (94.6 ft) downstream and 2.4 m (8.0 ft) behind the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 80.

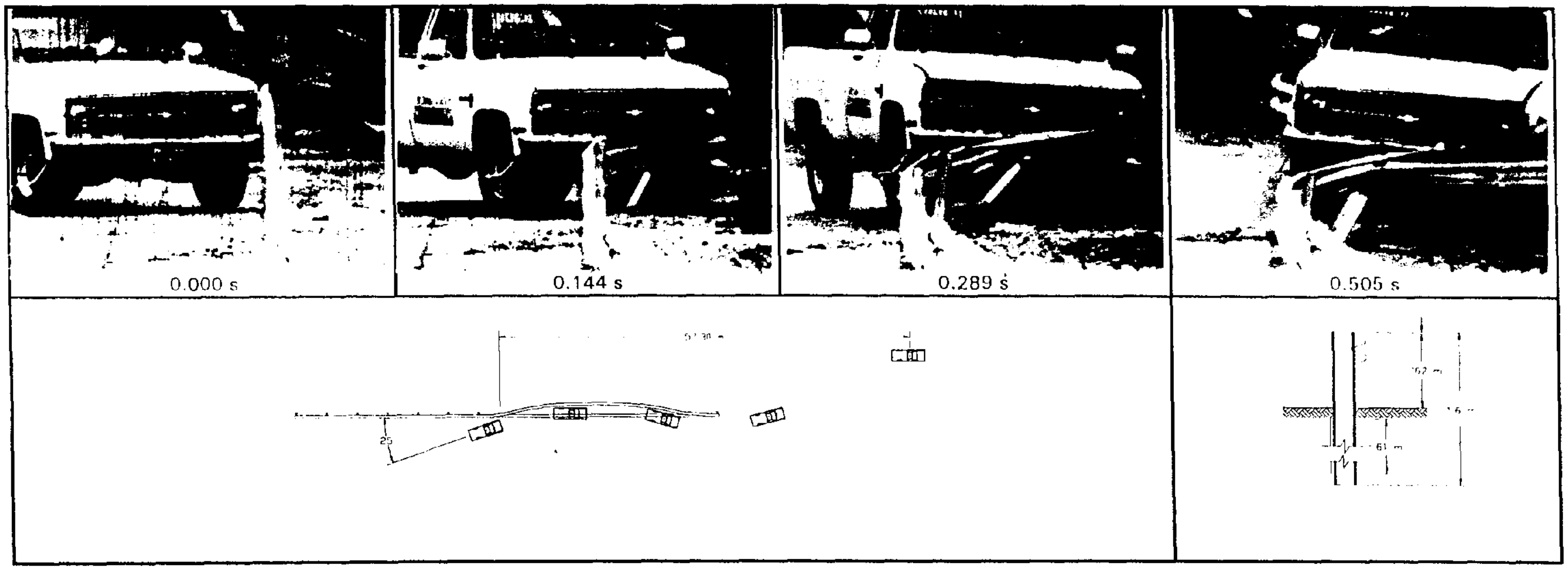
There was evidence of movement on all of the posts and the W-beam slipped over the tops of posts 5 through 13. The maximum permanent deformation of the W-beam was 1.8 m (5.9 ft). The vehicle was in contact with the installation from impact to the end of the guardrail. The left front, left rear, and right front tires of the vehicle overrode the guardrail and exited only when the end of the guardrail installation was reached. It is evident from reviewing the high-speed film that, had there been a longer run of guardrail, the vehicle would likely have vaulted over the guardrail completely, which is not acceptable.

Maximum exterior crush at the left front corner at bumper height of the vehicle was 259 mm (10.2 in), and there was no intrusion into or deformation of the occupant compartment. Damage was sustained to the front bumper, grill, hood, and along the entire left side the body panels were dented and scraped. There was slight damage to the right front corner where the vehicle came to rest against the next installation downstream.

12.4 W-BEAM, WEAK-POST (G2) GUARDRAIL SYSTEM
Test Number 471470-22 (NCHRP Report 350 test designation 2-11)

Test vehicle: 1985 Chevrolet Pickup	Impact speed: 71.0 km/h (44.1 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 26.1 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of 61.0 m (200 ft) of length-of-need section with a 7.62-m (25-ft) turned-down terminal at each of the two ends, for a total test installation length of 76.2 m (250 ft). The vehicle impacted the guardrail system at midspan between posts 4 and 5. As the vehicle impacted the guardrail installation, the W-beam rail element began to deform. Post 5 (first post downstream from impact), post 4 (first post upstream from impact), and post 6 (second post downstream from impact) began to deflect. The left front tire of the vehicle contacted post 5, resulting in the front tires being turned toward the guardrail. The vehicle began to redirect, the W-beam rail element went over the top of post 6, and then the



General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-21
Date	11/17/93
Test Article	
Type	Guardrail w/Turned-Down
Name or Manufacturer	Weak-Post W-Beam (G2)
Installation Length (m)	61 (200 ft)
Size and/or Dimension and Material of Key Elements	76 cm (30 in) mount height W-Beam (ARTBA RE-3-73) S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Chevrolet Custom 20
Mass (kg) Curb	2000 (4405 lb)
Test Inertial	2000 (4405 lb)
Dummy	76 (167 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	99.8 (62.0 mi/h)
Angle (deg)	24.4
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	5.0 (16.4 ft/s)
y-direction	3.0 (10.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.2
y-direction	4.5
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-3.0
y-direction	3.2
z-direction	-3.0

Test Article Deflections (m)	
Dynamic	2.4 (7.9 ft)
Permanent	1.8 (5.9 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4 & 11LD2
CDC	11FLEK3 & 11LDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	259 (10.2 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	-29
Max. Pitch Angle (deg)	7
Max. Yaw Angle (deg)	34

Figure 80. Summary of results for test 471470-21.

front of the vehicle impacted post 6. Maximum dynamic deflection of the guardrail was 1.4 m (4.5 ft). The vehicle was traveling parallel to the installation at 38.0 km/h (23.6 mi/h). The front of the vehicle impacted post 7. As the vehicle continued to be redirected, the vehicle began to turn counterclockwise toward the rail because of the orientation of the front tires. The vehicle separated from the guardrail traveling at an estimated exit speed and angle of 25.7 km/h (16.0 mi/h) and 9.5 degrees. The vehicle came to rest 17.3 m (56.7 ft) downstream from the initial point of impact adjacent to the face of the rail element. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 81.

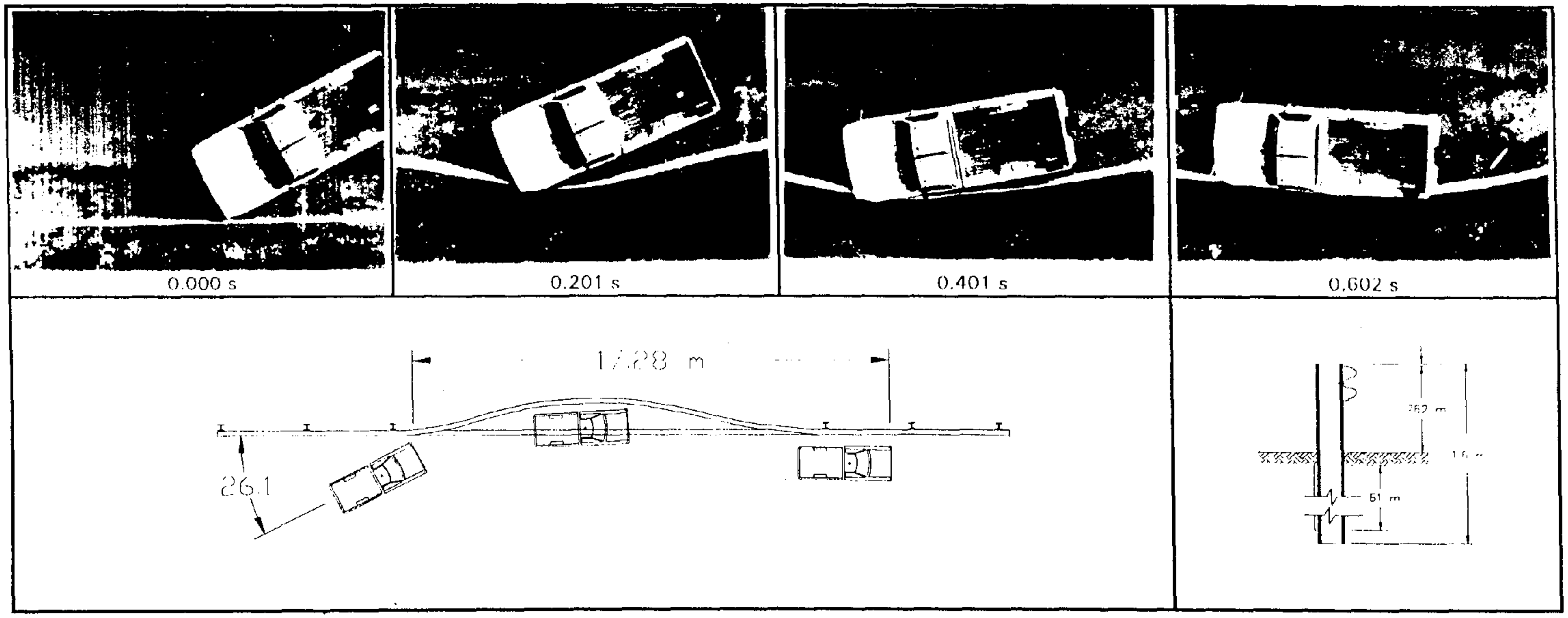
There was evidence of movement on the first 9 posts. The W-beam slipped over the tops of posts 5 through 7, and the maximum permanent deformation of the W-beam was 1.3 m (4.2 ft). The vehicle was in contact with the installation for a total length of 15.7 m (51.7 ft).

Maximum exterior crush at the left front corner at bumper height of the vehicle was 231 mm (9.1 in), and there was no intrusion into or deformation of the occupant compartment. Damage was sustained to the front bumper, grill, hood, and left front lower A-arm assembly. Along the left side the body panels were dented and scraped through the driver's door.

12.5 BOX-BEAM (G3) GUARDRAIL SYSTEM
Test Number 471470-33 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 Chevrolet 2500 Pickup	Impact speed: 95.2 km/h (59.1 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 25.5 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of a 45.7-m- (150-ft-) long section of the box-beam (G3) guardrail with a 15-m- (49.2-ft-) long telescoping tube terminal (WYBET) on the impact end and a turned down terminal on the downstream end. The vehicle impacted the length-of-need section 0.9 m (2.9 ft) upstream of post 15. As the vehicle impacted the installation, the box-beam rail element began to deflect and redirection of the vehicle began. The right front tire contacted post 15, then post 16, and the wheels began to steer sharply toward the guardrail. The left front tire caught post 17 and post 18. The vehicle became parallel with the installation traveling at 73.0 km/h (45.4 mi/h). Maximum dynamic deflection of the box-beam rail element was 1.15 m (3.8 ft) as the vehicle contacted post 19. The vehicle lost contact with the installation traveling at 44.8 km/h (27.8 mi/h) and an exit angle of approximately 0.7 degree toward the guardrail. As the vehicle exited the installation, it continued to yaw counterclockwise toward the guardrail. The vehicle contacted the guardrail a second time and subsequently came to rest with the nose of the vehicle against the guardrail 26 m (85 ft) down from the initial point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 82.

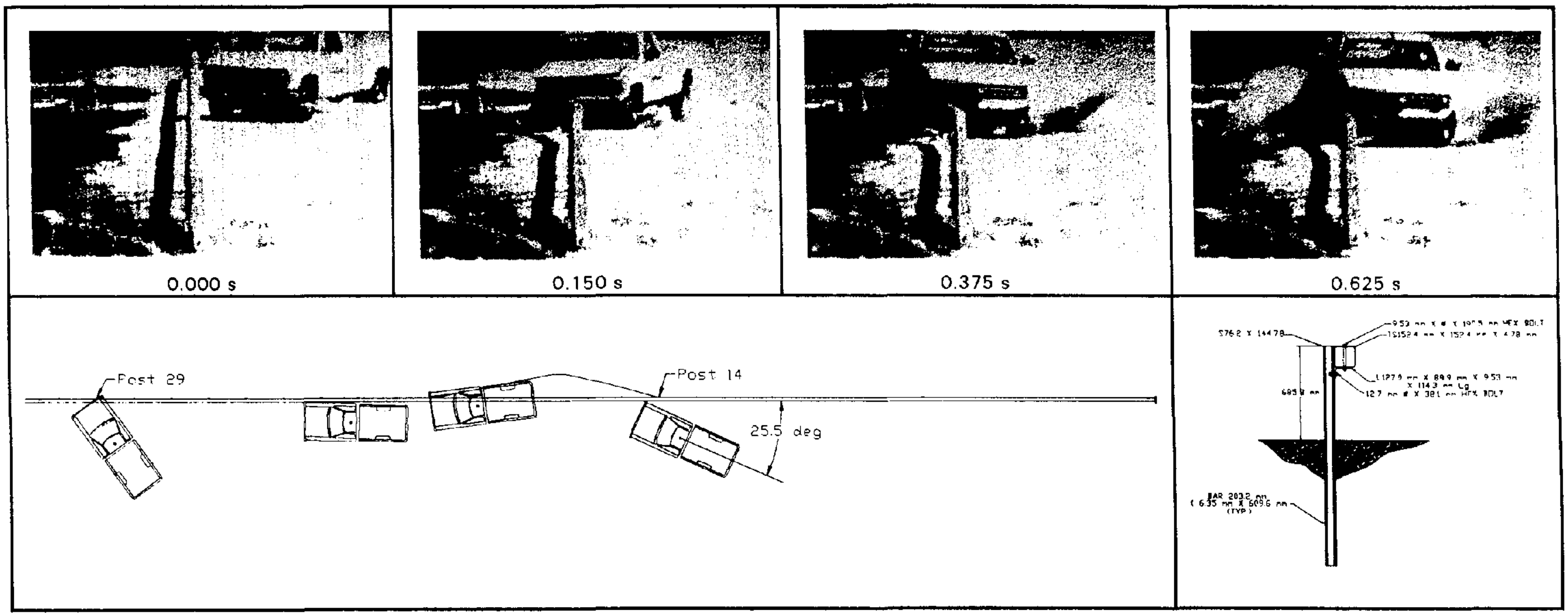


General Information	
Test Agency	Texas Transportation Institute
Test No.	7147-22
Date	1/6/94
Test Article	
Type	Guardrail w/Turned-Down
Name or Manufacturer	Weak-Post W-Beam (G2)
Installation Length (m)	76.2 (250 ft)
Size and/or Dimension and Material of Key Elements	76 cm (30 in) mount ht W-Beam (ARTBA RE-3-73) S3x5.7 Post
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1985 Chevrolet Custom 20
Mass (kg) Curb	2000 (4405 lb)
Test Inertial	2000 (4405 lb)
Dummy	76 (167 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	71.0 (44.1 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	25.7 (16.0 mi/h)
Angle (deg)	9.5
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.6 (14.9 ft/s)
y-direction	3.3 (10.7 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.8
y-direction	3.1
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-3.1
y-direction	2.6
z-directon	-1.6

Test Article Deflections (m)	
Dynamic	1.4 (4.5 ft)
Permanent	1.3 (4.2 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ3 & 11LD2
CDC	11FLEK2 & 11LDEW2
Interior	
OCDI	RS0000000
Maximum Exterior Vehicle Crush (mm)	231 (9.1 in)
Max. Occ. Compart. Deformation (mm)	0
Post-Impact Behavior	
Max. Roll Angle (deg)	9
Max. Pitch Angle (deg)	-3
Max. Yaw Angle (deg)	37

Figure 81. Summary of results for test 471470-22.



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-33
Date	04/13/95
Test Article	
Type	Guardrail
Name or Manufacturer	G3 Box Beam
Installation Length (m)	68 m (223 ft)
Size and/or Dimension and Material of Key Elements	TS6x6x.188 Box Beam on S3x5.7 Steel Posts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1980 (4361 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	95.2 (59.1 mi/h)
Angle (deg)	25.5
Exit Conditions	
Speed (km/h)	44.8 (27.8 mi/h)
Angle (deg)	0.7 toward rail
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	6.3 (20.7 ft/s)
y-direction	0.9 (3.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-5.8
y-direction	-10.7
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-4.8
y-direction	2.6
z-direction	-4.1

Test Article Deflections (m)	
Dynamic	1.15 (3.8 ft)
Permanent	0.74 (2.4 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ4
CDC	01FREK2 & 01RYES3
Interior	
OCDI	RF0000000
Maximum Exterior Vehicle Crush (mm)	530 (20.9 in)
Max. Occ. Compart. Deformation (mm)	9 (0.4 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-7
Max. Pitch Angle (deg)	2
Max. Yaw Angle (deg)	-33

Figure 82. Summary of results for test 471470-33.

There were tire marks on the face of the box-beam rail element from posts 15 through 21, and on posts 15 through 20. The box-beam rail element was separated from posts 16 through 20, and these posts were bent at ground level. Lateral deflections occurred at posts 12 through 22. Maximum dynamic deflection of the box-beam rail element was 1.15 m (3.8 ft). Maximum permanent deformation of the installation was 0.74 m (2.4 ft) near post 16. Total length of contact of the vehicle with the installation was 12.6 m (41.3 ft).

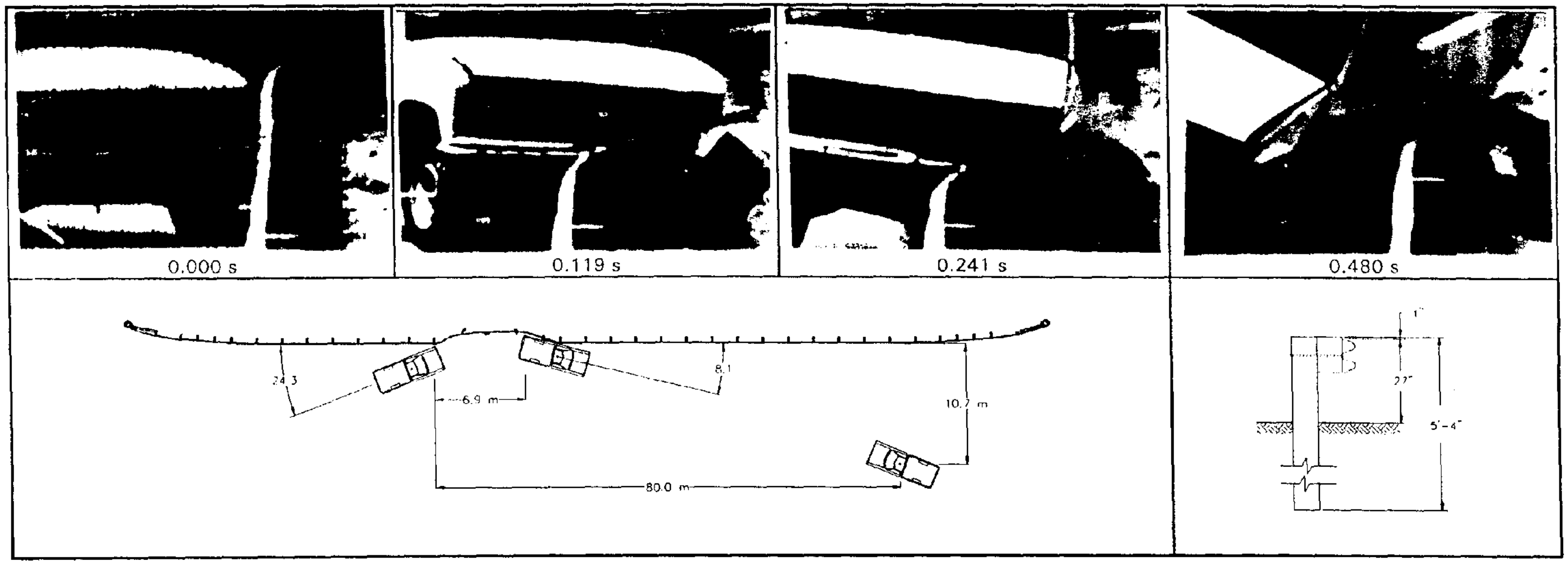
The vehicle's right lower A-arm, stabilizer bar, and tie rod ends on the right side were damaged. The front bumper, grill, right front quarter panel, right door, right rear quarter panel, and the right front wheel were also damaged. Maximum exterior crush at the right front corner of the vehicle was 530 mm (20.9 in), and maximum deformation of the occupant compartment was 9 mm (0.4 in) at the instrument panel area on the passenger side.

12.6 W-BEAM, WOOD-POST (G4(2W)) GUARDRAIL SYSTEM
Test Number 471470-26 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 Chevrolet 2500 Pickup	Impact speed: 100.8 km/h (62.6 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 24.3 degrees
Gross static weight: 2074 kg (4568 lb)	

The test installation consisted of a 45.7-m- (150-ft-) long section of the standard G4(2W) guardrail with a MELT at the upstream end and a standard breakaway cable terminal (BCT) at the downstream end, for a total installation length of 68.6 m (225 ft). The vehicle impacted the length-of-need section 0.61 m (2 ft) upstream of post 14, or 4.5 m (14.5 ft) upstream of the splice at post 16. As the vehicle impacted the guardrail, the W-beam rail element began to deform and post 14 began to displace laterally. The vehicle impacted post 14 shortly afterwards, and redirection of the vehicle began. The front of the vehicle contacted post 15 and then the tire contacted the post. The vehicle contacted post 16 and the tire contacted post 16. Shortly after that, the left front wheel assembly separated from the vehicle and the blockout on post 16 split. The rear of the vehicle made contact with the guardrail. The vehicle contacted post 17 and the vehicle was parallel with the installation traveling at 74.3 km/h (46.3 mi/h). Maximum deflection of the W-beam rail of 0.82 m (2.7 ft) occurred near post 16. The vehicle lost contact with the installation traveling at a speed of 70.8 km/h (44.0 mi/h) and at an exit angle of 8.1 degrees. As the vehicle exited the rail, it had rolled 25 degrees counterclockwise and was yawing clockwise. Maximum roll angle attained was 39 deg. As the damaged front end of the vehicle contacted the ground, the vehicle righted itself and began to yaw counterclockwise, subsequently coming to rest 80 m (263 ft) downstream and 10.7 m (35 ft) forward of the point of impact. The vehicle had yawed approximately 150 degrees. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 83.

The bolts were pulled out of the W-beam rail element at posts 15 and 16, and the blockout on post 16 was split. None of the posts broke off, but some posts were pushed back. The W-beam rail element was deformed from posts 13 through 18 and there was evidence of tire contract with posts 14 through 17. Maximum dynamic deflection of the



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-26
Date	05/25/94
Test Article	
Type	Guardrail
Name or Manufacturer	G4(2W)
Installation Length (m)	69 m (225 ft)
Size and/or Dimension and Material of Key Elements	G4(2W) Guardrail System with MELT End Terminals
Soil Type and Condition .	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1849 (4073 lb)
Test Inertial	2000 (4405 lb)
Dummy ..	75 (165 lb)
Gross Static	2074 (4568 lb)

Impact Conditions	
Speed (km/h)	100.8 (62.6 mi/h)
Angle (deg)	24.3
Exit Conditions	
Speed (km/h)	70.8 (44.0 mi/h)
Angle (deg)	8.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.5 (24.5 ft/s)
y-direction	5.9 (19.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-11.6
y-direction	11.4
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.1
y-direction	6.8
z-direction	9.1

Test Article Deflections (m)	
Dynamic	0.82 (2.7 ft)
Permanent	0.69 (2.25 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ5
CDC	11FLEK2 & 11LDLW4
Interior	
OCDI	FS0100000
Maximum Exterior Vehicle Crush (mm) ..	370 (14.6 in)
Max. Occ. Compart. Deformation (mm) ...	44 (1.7 in)
Post-Impact Behavior	
Max. Roll Angle (deg) ..	-40
Max. Pitch Angle (deg) .	-12
Max. Yaw Angle (deg) .	47

Figure 83. Summary of results for test 471470-26.

guardrail during the test was 0.82 m (2.7 ft) near post 16. Maximum permanent deformation of the guardrail was 0.69 m (2.25 ft) between posts 15 and 16. The vehicle was in contact with the guardrail system for a total length of 6.9 m (22.7 ft).

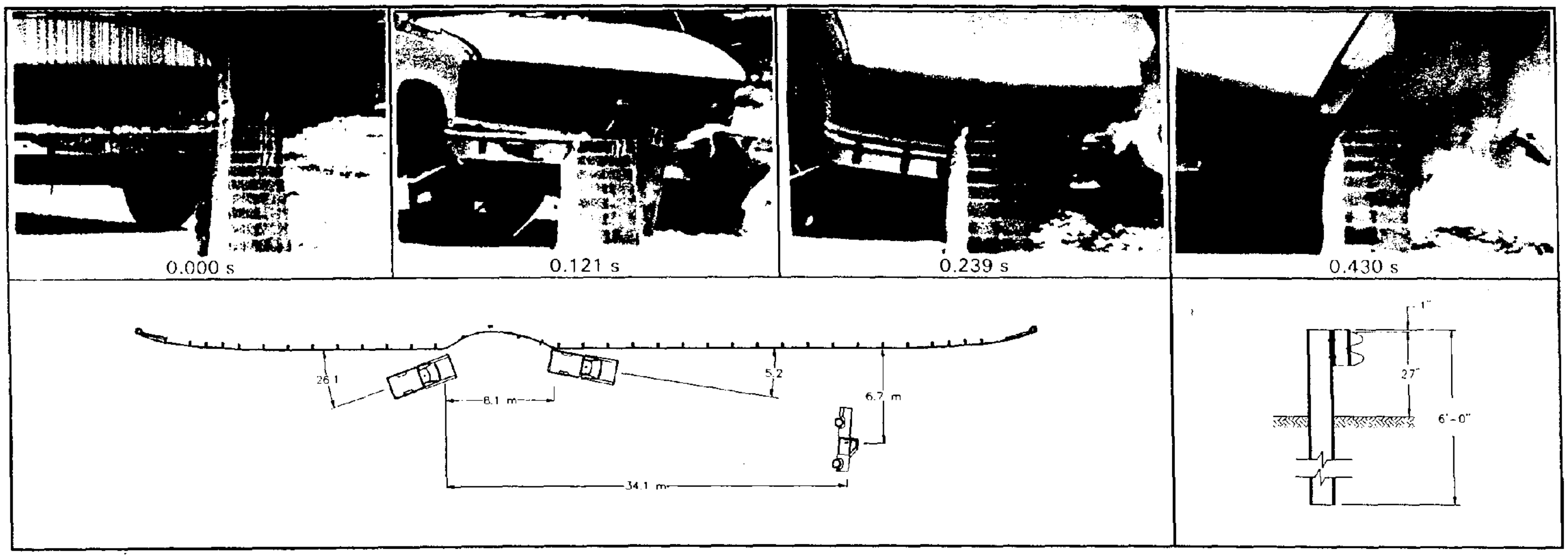
The vehicle's stabilizer bar, upper and lower A-arms, and tie rods on the left side were damaged and the frame at the left front was bent. The left front spindle, wheel, and tire were separated from the vehicle. The front bumper, grill, and entire left side were also damaged. Maximum exterior crush at the left front corner of the vehicle was 370 mm (14.6 in) at bumper height. There was 44 mm (1.7 in) deformation of the occupant compartment in the floor pan area near the transmission tunnel.

12.7 W-BEAM, STEEL-POST (G4(1S)) GUARDRAIL SYSTEM Test Number 471470-27 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1988 Chevrolet 2500 Pickup	Impact speed: 101.4 km/h (62.6 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 26.1 degrees
Gross static weight: 2075 kg (4570 lb)	

The test installation consisted of a 45.7-m- (150-ft-) long section of the standard G4(1S) guardrail with a MELT at the upstream end and a standard BCT at the downstream end, for a total installation length of 68.6 m (225 ft). The vehicle impacted the length-of-need section 0.61 m (2 ft) upstream of post 14, or 4.5 m (14.5 ft) upstream of the splice at post 16. As the vehicle impacted the guardrail, the W-beam rail element began to deform, and posts 13 and 14 began to displace laterally. The front of the vehicle impacted post 14 shortly thereafter, the left front tire of the vehicle contacted post 15, and, as the vehicle continued forward, the tire aired out and began to fold under. Redirection of the vehicle began as the body of the vehicle began to bow upward in the center (between the cab and bed). The left front tire snagged on post 16 and the body of the vehicle began to bow substantially. The rear of the vehicle made contact with the W-beam rail and then the vehicle was parallel with the installation traveling at 66.0 km/h (41.0 mi/h). As the vehicle traveled past post 17, the left front tire made slight contact with the post. Maximum deflection of the W-beam rail was 1.01 m (3.3 ft). The vehicle lost contact with the installation traveling at a speed of 58.7 km/h (36.5 mi/h) and at an exit trajectory of 5.2 degrees. As the vehicle exited the rail, it had rolled 28 degrees counterclockwise and was yawing clockwise. As the damaged front end of the vehicle contacted the ground, the vehicle continued to roll onto its left side and subsequently slid to rest on its left side 34 m (112 ft) downstream and 6.7 m (22 ft) forward of the point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 84.

The MELT anchor on the upstream end had pulled up slightly and moved laterally 44.5 mm (1.75 in). The buffered end nose was pulled off the end post (post 1). The bolts were pulled out of the W-beam rail element at posts 15, 16, and 17, and the posts and blockouts were bent. All the steel posts upstream of impact were disturbed with measurable displacements. The W-beam rail element was deformed between posts 14 through 18 and there was evidence of tire contract with posts 15 through 17. Maximum dynamic deflection



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-27
Date	06/09/94
Test Article	
Type	Guardrail
Name or Manufacturer	G4(1S)
Installation Length (m)	69 m (225 ft)
Size and/or dimension and material of key elements	G4(2W) Guardrail System with MELT End Terminals
Soil Type and Condition .	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1988 Chevrolet 2500
Mass (kg) Curb	1944 (4282 lb)
Test Inertial	2000 (4405 lb)
Dummy ..	75 (165 lb)
Gross Static	2075 (4570 lb)

Impact Conditions	
Speed (km/h)	101.4 (63.0 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	58.7 (36.5 mi/h)
Angle (deg)	5.2
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.5 (24.8 ft/s)
y-direction	4.9 (16.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-7.8
y-direction	6.2
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.0
y-direction	4.7
z-direction	3.9

Test Article Deflections (m)	
Dynamic	0.91 (3.0 ft)
Permanent	0.64 (2.1 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ6 9L&T3
CDC	11FLEK3 & 00LDAO3
Interior	
OCDI	LF0100000
Maximum Exterior Vehicle Crush (mm) ..	570 (22.4 in)
Max. Occ. Compart. Deformation (mm) ...	53 (2.1 in)
Post-Impact Behavior	
Max. Roll Angle (deg) ..	-119
Max. Pitch Angle (deg) .	-19
Max. Yaw Angle (deg) .	79

Figure 84. Summary of results for test 47147-27.

of the guardrail during the test was 1.01 m (3.3 ft). Maximum permanent deformation of the guardrail was 0.73 m (2.4 ft) between posts 15 and 16. The vehicle was in contact with the guardrail system for a total length of 8.1 m (26.5 ft).

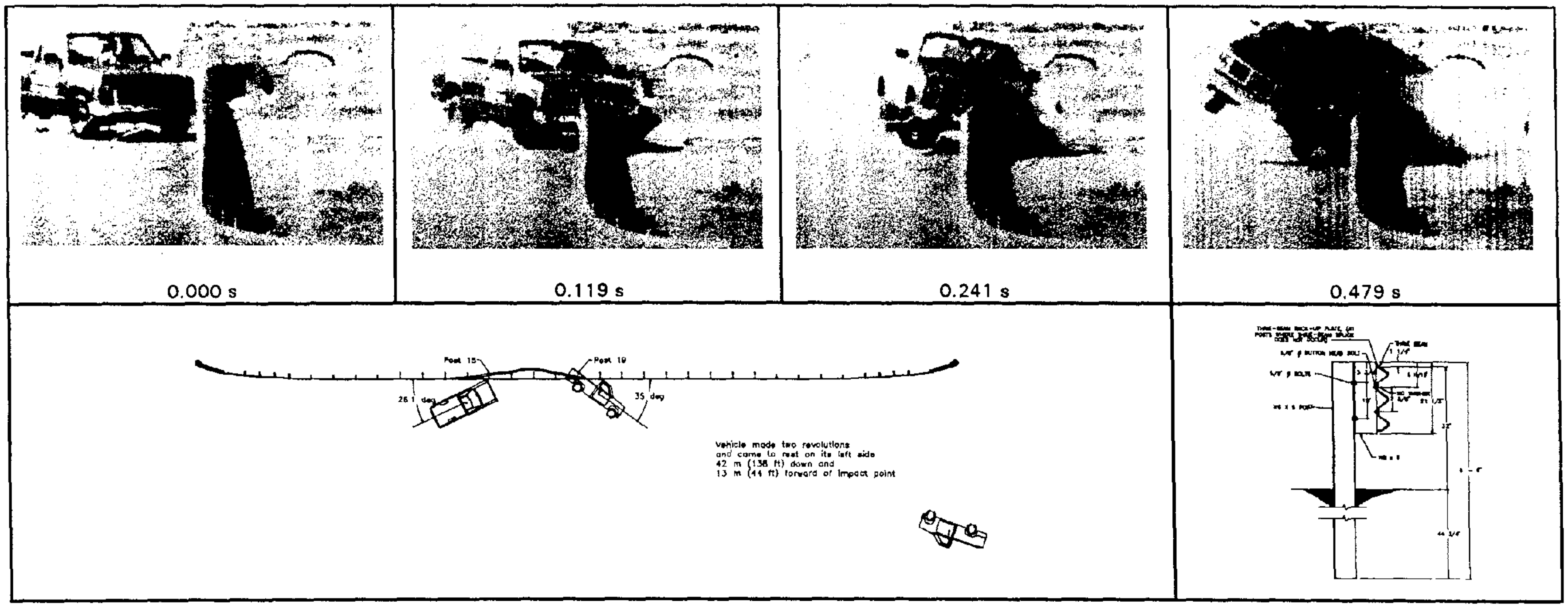
The vehicle's stabilizer bar, upper and lower A-arms, and tie rods on the left side were damaged and the frame at the left front was bent. The left front spindle, wheel, and tire were damaged. The front bumper, grill, hood, radiator, windshield, and entire left side also were damaged. Maximum exterior crush at the left front corner of the vehicle was 570 mm (22.4 in) at bumper height. There was 53 mm (2.1 in) deformation of the occupant compartment in the floor pan area on the driver's side.

12.8 THRIE-BEAM (G9) GUARDRAIL SYSTEM Test Number 471470-31 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1990 GMC 2500 Pickup	Impact speed: 102.5 km/h (63.5 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 26.1 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of a 30.5-m- (100-ft-) long length-of-need section of the standard thrie-beam (G9) guardrail with a 1.9-m- (6-ft, 3-in-) long transition section from the thrie-beam to the W-beam rail element, a 3.8-m- (12-ft, 6-in-) long section of standard steel-post, W-beam G4(1S) guardrail and a 11.4-m- (37-ft, 6-in-) long MELT at each end, for a total installation length of 64.8 m (212 ft, 6 in). The vehicle impacted the length-of-need section 102 mm (4.0 in) upstream of post 15. As the vehicle impacted the installation, the thrie-beam rail element began to deflect and redirection of the vehicle began. The left front wheel began to steer sharply toward the guardrail, and posts 16 and 17 began to rotate about their vertical axes. The left front tire caught the flanges of post 16 and post 17. Maximum dynamic deflection of the thrie-beam rail element of 1.07 m (3.5 ft) occurred between posts 17 and 18. The vehicle became parallel with the installation traveling at 67.5 km/h (41.9 mi/h). The rear of the vehicle contacted the thrie-beam rail element. The vehicle lost contact with the installation traveling at a speed of 54.5 km/h (33.9 mi/h), an exit angle of approximately 35 degrees, and a roll angle of roughly -45 degrees. As the vehicle exited the installation, it continued to roll counterclockwise and yaw clockwise. The vehicle rolled two and a quarter revolutions and came to rest on its left side 42 m (138 ft) down and 13 m (44 ft) forward of the initial point of impact, with the front of the vehicle facing the direction of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 85.

There were tire marks on the face of the thrie-beam rail element from posts 15 through 19, and on the face of posts 16 and 17. The thrie-beam rail element was separated from post 16 and the flanges on post 17 showed evidence of wheel contact. Posts 15 through 19 were twisted severely. The lateral deflections occurred at posts 13 through 20. Maximum dynamic deflection of the thrie-beam rail element was 1.07 m (3.5 ft). Maximum permanent



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-31
Date	04/14/95
Test Article	
Type	Guardrail
Name or Manufacturer	G9 Thrie Beam
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Thrie Beam on W6x9 Posts with M14x17.2 Blockouts
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1990 GMC 2500
Mass (kg) Curb	2094 (4612 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	102.2 (63.5 mi/h)
Angle (deg)	26.1
Exit Conditions	
Speed (km/h)	54.5 (33.9 mi/h)
Angle (deg)	approx. 35
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	8.0 (26.4 ft/s)
y-direction	4.9 (16.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-7.0
y-direction	6.3
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.4
y-direction	4.5
z-direction	-3.3

Test Article Deflections (m)	
Dynamic	1.07 (3.5 ft)
Permanent	0.64 (2.1 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4 & 9L&T5
CDC	11FLEK2 & 80TZDO5
Interior	
OCDI	RF0200000
Maximum Exterior Vehicle Crush (mm)	420 (16.5 in)
Max. Occ. Compart. Deformation (mm)	114 (4.5 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-810
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	221

Figure 85. Summary of results for test 471470-31.

deformation of the installation was 0.64 m (2.1 ft) just upstream of post 17. Total length of contact of the vehicle with the installation was 8.2 m (26.8 ft).

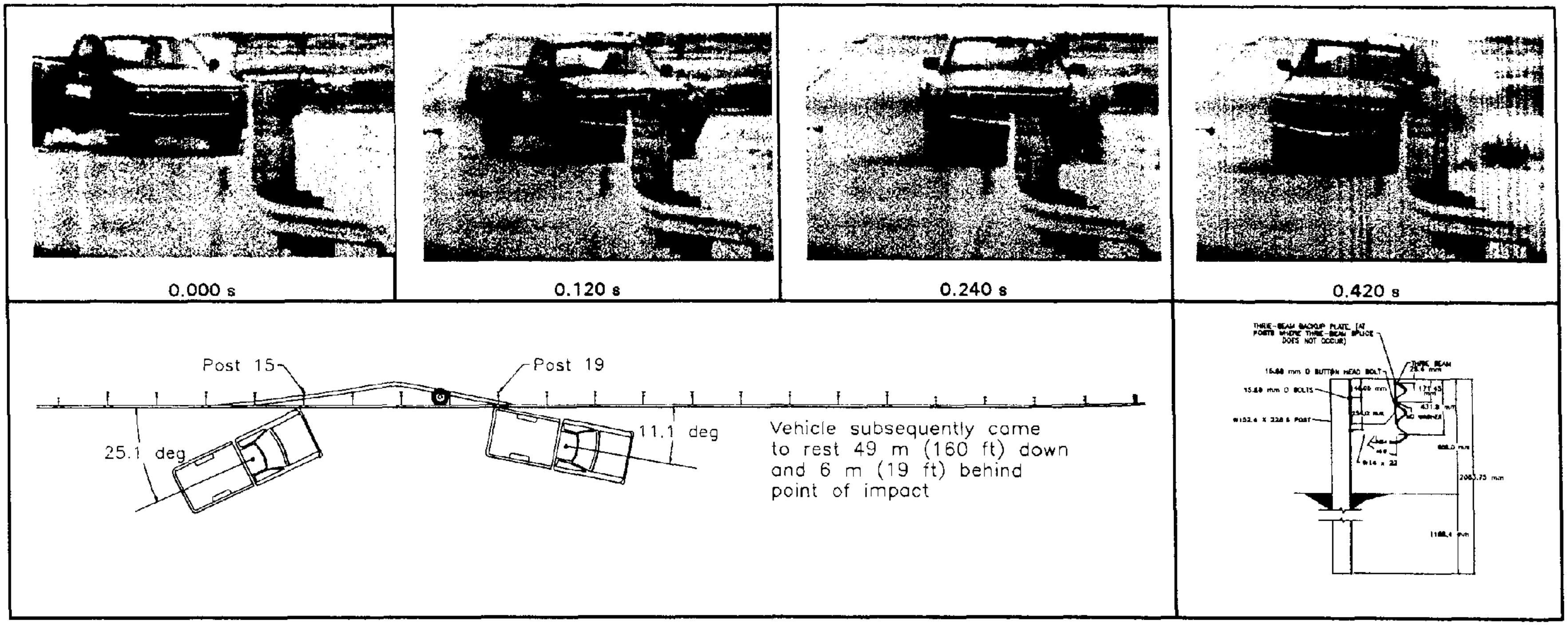
The vehicle's upper and lower A-arms, stabilizer bar, frame, and tie rod ends on the left side were damaged. The front bumper, grill, hood, left front quarter panel, both doors, and the left front and rear wheels were also damaged. The windshield and windows were broken and the roof was damaged because of the rollover. Maximum exterior crush at the left front corner of the vehicle was 420 mm (16.5 in) and maximum deformation of the occupant compartment was 144 mm (4.5 in) downward from the roof area on the passenger side.

12.9 MODIFIED THRIE-BEAM GUARDRAIL SYSTEM
Test Number 471470-30 (NCHRP Report 350 test designation 3-11)

Test vehicle: 1989 GMC 2500 Pickup	Impact speed: 100.2 km/h (62.3 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 25.1 degrees
Gross static weight: 2076 kg (4573 lb)	

The test installation consisted of a 30.5-m- (100-ft-) long length-of-need section of the modified thrie-beam guardrail with a 1.9-m- (6-ft, 3-in-) long transition section from the thrie-beam to the W-beam rail element, a 3.8-m- (12-ft, 6-in-) long section of standard steel-post, W-beam G4(1S) guardrail and a 11.4-m- (37-ft, 6-in-) long MELT at each end for a total installation length of 64.8 m (212 ft, 6 in). The vehicle impacted the length-of-need section at post 15. As the vehicle impacted the installation, the thrie-beam guardrail began to deflect and redirection of the vehicle began. The left front tire made contact with the flange and face of post 16, which caused the wheel to turn outward (or counterclockwise). The vehicle continued forward as posts 17 and 18 began to rotate about their vertical axes. The left front wheel assembly caught the flange at post 17 and the entire wheel assembly was torn from the axle. The front of the vehicle reached post 18 and the rear of the vehicle made contact with the thrie-beam rail element. The vehicle became parallel with the installation traveling at 74.3 km/h (46.2 mi/h). The vehicle lost contact with the installation traveling at a speed of 67.4 km/h (41.9 mi/h) and an exit angle of approximately 11.1 degrees. The vehicle brakes were applied as the vehicle exited the test area, and subsequently came to rest 49 m (160 ft) down and 6 m (19 ft) behind the initial point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 86.

There were tire marks on the face of the thrie-beam rail element from posts 15 through 19, and on the face of post 16 and the back side of post 17. The thrie-beam rail element was separated from post 17 and the flanges on post 17 showed evidence of wheel contact. Posts 16, 17, and 18 were twisted severely. Lateral deflections occurred at posts 14 through 20. Maximum dynamic deflection of the thrie-beam rail element was 1.02 m (3.4 ft). Maximum permanent deformation of the installation was 0.61 m (2.0 ft) just upstream of post 17. Total length of contact of the vehicle with the installation was 8.0 m (26.1 ft).



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-30
Date	01/11/95
Test Article	
Type	Guardrail
Name or Manufacturer	Modified Thrie beam
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Thrie Beam on W6x9 Post and M14x18 Spacer with Cutout
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 GMC 2500 Pickup
Mass (kg) Curb	2043 (4500 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	100.2 (62.3 mi/h)
Angle (deg)	25.1
Exit Conditions	
Speed (km/h)	67.4 (41.9mi/h)
Angle (deg)	11.1
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	7.8 (25.6 ft/s)
y-direction	5.2 (17.1 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-9.7
y-direction	9.0
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.2
y-direction	5.2
z-direction	-2.9

Test Article Deflections (m)	
Dynamic	1.02 (3.4 ft)
Permanent	0.61 (2.0 ft)
Vehicle Damage	
Exterior	
VDS	11LFQ4
CDC	11FLEK3 & 11LYEW4
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	430 (16.9 in)
Max. Occ. Compart. Deformation (mm)	16 (0.6 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-9
Max. Pitch Angle (deg)	-7
Max. Yaw Angle (deg)	36

Figure 86. Summary of results for test 471470-30.

The vehicle's upper and lower A-arms, stabilizer bar, frame, tie rod ends, and spindle on the left side were damaged. The left front wheel assembly was torn from the vehicle's axle. The front bumper, grill, left front quarter panel, and both doors were also damaged. Maximum exterior crush at the left front corner of the vehicle was 430 mm (16.9 in) and there was deformation at the floor pan area of 16 mm (0.6 in).

12.10 SUMMARY OF FINDINGS

12.10.1 Cable (G1) Guardrail System

The vehicle was successfully contained and smoothly redirected by the cable (G1) guardrail system under test level 3 conditions. The maximum dynamic deflection of the guardrail was 2.4 m (7.8 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained moderate damage with no intrusion or deformation into the passenger compartment. The vehicle remained upright and stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of 2.0 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the cable (G1) guardrail system was considered satisfactory according to guidelines set forth in NCHRP Report 350, as shown in table 32.

It should be noted that the impact speed of 95.1 km/h (59.1 mi/h) was lower than the target impact speed of 100 km/h (62.2 mi/h). However, the impact angle of 26.7 degrees was higher than the target impact angle of 25 degrees. Consequently, the impact severity (IS) value of the test was 141.2 kJ (104.1 kip-ft), which was actually higher than the nominal IS value of 138.1 kJ (101.9 kip-ft) for the target impact speed and angle. Furthermore, based on the test results, there is no reason to believe that the cable (G1) guardrail system would perform any differently at the target impact speed and angle.

12.10.2 W-Beam, Weak-Post (G2) Guardrail System

The W-beam, weak-post (G2) guardrail system was crash tested under both test level 3 (test no. 471470-21) and test level 2 (test no. 471470-22) conditions. Summaries of the results of the two tests are shown in tables 33 and 34, respectively.

The W-beam, weak-post (G2) guardrail system failed to contain and redirect the impacting vehicle at test level 3 conditions. The left front, left rear, and right front tires of the vehicle overrode the guardrail and exited only when the end of the guardrail installation was reached. It is evident from reviewing the high-speed film that, had there been a longer run of guardrail, the vehicle would likely have vaulted over the guardrail completely, which is not acceptable. The best scenario is for the vehicle to straddle the guardrail until it comes to rest.

Table 32. Assessment of results of test with cable (G1) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-28 | Test Date: 11/15/94

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle. The vehicle did not penetrate or go over the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to pose any undue hazard to adjacent traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal if any intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.3 m/s Longitudinal Ridedown Acceleration = -4.0 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 2 degrees, which was less than 60 percent of the test impact angle of 26.7 degrees.	Pass

Table 33. Assessment of results of test with W-beam, weak-post (G2) guardrail system (test level 3).

Test Agency: Texas Transportation Institute | Test No.: 471470-21 | Test Date: 09/09/93

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The left front, left rear, and right front tires of the vehicle overrode the guardrail before reaching the end of the test installation.	Fail
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	The only debris to separate a significant distance from the installation were the washers used in attaching the W-beam to the posts. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable throughout the test period; however, it did mount the installation.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was no vehicle intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.9 m/s Longitudinal Ridedown Acceleration = -4.2 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The vehicle remained on top of the guardrail until the end of the installation.	Pass

Table 34. Assessment of results of test with W-beam weak-post (G2) guardrail system (test level 2).

Test Agency: Texas Transportation Institute | Test No.: 471470-22 | Test Date: 01/06/94

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There was no detached elements or debris to pose any undue hazard to adjacent traffic. There was no deformation or intrusion into the occupant compartment.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was no vehicle intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.6 m/s Longitudinal Ridedown Acceleration = -4.8 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle of 9.5 degrees was less than 60 percent of the test impact angle.	Pass

Otherwise, the G2 guardrail system performed well with respect to the other evaluation criteria. There were no debris or detached elements from the installation that would pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact though it was astride the guardrail. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic. The occupant risk factors were all well within the desirable limits set forth in NCHRP Report 350.

The W-beam, weak-post (G2) guardrail system successfully contained and redirected the impacting vehicle under test level 2 conditions. There were no debris or detached elements from the installation that would pose undue hazard to adjacent traffic. The vehicle sustained moderate damage with no deformation or intrusion into the passenger compartment. The vehicle remained upright and relatively stable during and after the impact. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic. The occupant risk factors were all well within the desirable limits set forth in NCHRP Report 350.

In summary, the impact performance of the W-beam, weak-post (G2) guardrail system was considered unsatisfactory from the structural adequacy standpoint under NCHRP Report 350 test level 3 conditions, but performed satisfactorily under test level 2 conditions.

12.10.3 Box-Beam (G3) Guardrail System

The box-beam (G3) guardrail system successfully contained and redirected the vehicle. The maximum dynamic deflection of the guardrail was 1.15 m (3.8 ft). There were no detached elements or debris to exhibit an undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation into the passenger compartment. The vehicle remained upright and stable during the impact sequence and after exiting the guardrail. The trajectory of the vehicle was judged to have posed minimal, if any, potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of approximately 0.7 degree toward the guardrail. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350.

The impact speed of 95.2 km/h (59.1 mi/h) was slightly slower than the lower tolerance limit of 96 km/h (59.7 mi/h) (i.e., for a nominal impact speed of 100 km/h (62.2 mi/h) and a tolerance of -4 km/h (-2.5 mi/h)). The impact angle of 25.5 degrees was higher than the nominal impact angle of 25 degrees. The resulting IS of 129.6 kJ (95.6 kip-ft) was above the lower IS tolerance limit of 127.3 kJ (93.9 kip-ft) (i.e., for a nominal IS of 138.1 kJ (101.9 kip-ft) and a tolerance of -10.8 kJ (-8.0 kip-ft)). Furthermore, there is no reason to believe that the box-beam (G3) guardrail system would have performed any differently with a slightly higher impact speed.

In summary, the impact performance of the box-beam (G3) guardrail system was considered satisfactory according to evaluation criteria set forth in NCHRP Report 350, as shown in table 35.

Table 35. Assessment of results of test with box-beam (G3) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-33 | Test Date: 04/13/95

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle through controlled lateral deflection. The vehicle did not penetrate or go over the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation into the occupant compartment that was not considered life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relativley stable during the collision and after exiting the test installation.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal, if any, intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 6.3 m/s Longitudinal Ridedown Acceleration = -5.8 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 0.7 degrees toward the guardrail.	Pass

12.10.4 W-Beam, Strong-Post (G4) Guardrail Systems

The W-beam, strong-post (G4) guardrail system was crash tested for both wood-post G4(2W) and steel-post G4(1S) systems. Summaries of the results are presented in tables 36 and 37, respectively.

In the test with the G4(2W) guardrail system, the vehicle was successfully contained and smoothly redirected. The maximum dynamic deflection of the guardrail was 0.8 m (2.7 ft). There were no detached elements or debris to exhibit an undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation into the passenger compartment. The vehicle attained a maximum roll angle of 39 degrees, but remained upright during and after the impact sequence. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of 8.1 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the G4(2W) guardrail system was considered acceptable according to guidelines set forth in NCHRP Report 350.

In the test with the G4(1S) guardrail system, the vehicle was contained and redirected by the guardrail; but the vehicle rolled over onto its left side (impact side) after exiting from the test installation. The maximum dynamic deflection of the guardrail was 1.01 m (3.3 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained severe damage, mostly due to rolling over onto its left side. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of 5.2 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the G4(1S) guardrail system was considered unsatisfactory due to the rollover of the vehicle onto its left side after exiting from the test installation.

The initial concern with these two strong-post, W-beam guardrail systems was that the mounting height may not be high enough to prevent the 2000P vehicle from vaulting or going over the guardrail. It was theorized that the bumper of the 2000P vehicle could potentially override the W-beam rail element and that the front tire could ride up on a post, resulting in the vehicle vaulting or going over the guardrail. There was no indication of this problem in either of the two crash tests. However, it should be noted that there are wide variations in the bumper heights of 3/4-ton pickup trucks. The 1988 and 1989 Chevrolet 2500 pickup trucks used in these two crash tests were selected to have an average or representative bumper height and do not have the highest possible bumper heights. Thus, the results from these crash tests may not totally eliminate this potential concern.

The G4(2W) and G4(1S) guardrail systems are generally considered to be compatible in performance and are used interchangeably. However, the vehicle remained upright in the G4(2W) test, but rolled over on its side in the G4(1S) test. These two length-of-need strength tests were almost identical, including the setups of the test installations, the nominal impact conditions, and the test vehicles. This provided an opportunity to compare the performance of the two guardrail systems.

Table 36. Assessment of results of test with W-beam, wood-post (G4(2W)) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-26 | Test Date: 05/25/94

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle. The vehicle did not penetrate or go over the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation of the occupant compartment that was not considered life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal vehicle intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 7.5 m/s Longitudinal Ridedown Acceleration = -11.6 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle of 8.1 degrees was less than 60 percent of the test impact angle.	Pass

Table 37. Assessment of results of test with W-beam, steel-post (G4(1S)) guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-27 | Test Date: 06/09/94

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle. The vehicle did not penetrate or go over the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation of the occupant compartment that was not considered life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle rolled onto its left side after exiting the guardrail system.	Fail
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal vehicle intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 7.5 m/s Longitudinal Ridedown Acceleration = -7.9 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle of 5.2 degrees was less than 60 percent of the test impact angle.	Pass

Table 38 summarizes the test parameters and the behavior of the vehicles and the guardrail systems for these two tests. The impact conditions for the steel-post G4(1S) guardrail system were slightly more severe than those for the wood-post G4(2W) guardrail system, particularly for the impact angle (26.1 versus 24.3 degrees). The maximum dynamic deflection for the steel-post G4(1S) guardrail system was somewhat more than the wood-post G4(2W) guardrail system, 1.01 m (3.3 ft) versus 0.82 m (2.7 ft). The time and location of the maximum dynamic deflections were very similar as were the maximum permanent deflections. This difference in deflection could be partially attributed to the slightly higher impact speed and angle in the G4(1S) guardrail system test. Another possibility is that the G4(1S) guardrail system, with lower bending strength for the steel posts, has less lateral stiffness and thus allowed more deflection.

Table 38. Comparison between test results for the strong-post, W-beam systems.

DESCRIPTION	G4(1S) GUARDRAIL	G4(2W) GUARDRAIL
Impact Conditions		
Speed	101.4 km/h (63.0 mi/h)	100.8 km/h (62.6 mi/h)
Angle	26.1 deg	24.3 deg
Maximum Dynamic Deflection		
Deflection	1.01 m (3.3 ft)	0.82 m (2.7 ft)
Location	Near post 16	Near post 16
Time	0.365 s	0.371 s
Maximum Permanent Deflection		
Deflection	0.73 m (2.4 ft)	0.69 m (2.25 ft)
Location	Between posts 15 and 16	Between posts 15 and 16
Parallel with Installation		
Time	0.274 s	0.249 s
Speed	66.0 km\h (41.0 mi/h)	74.3 km/h (46.3 mi/h)
Distance to parallel	6.7 m (21.9 ft)	6.0 m (19.6 ft)
Exit from Installation		
Time	0.530 s	0.513 s
Speed	58.7 km/h (36.5 mi/h)	70.8 km/h (44.0 mi/h)
Angle	5.2 deg	8.1 deg
Roll Angle	-28 deg	-25 deg
Length of Contact	8.1 m (26.5 ft)	6.9 m (22.7 ft)
Maximum Roll Angle	90 deg	39 deg

The time to parallel for the G4(1S) guardrail system was slightly longer than that for the G4(2W) guardrail system, 0.274 s versus 0.249 s, and with a lower speed, 66.0 km/h (41.0 mi/h) versus 74.3 km/h (46.3 mi/h). The time to exit from the test installation was approximately the same for both guardrail systems, but the exit speed and angle were lower and the total length of contact was longer for the G4(1S) guardrail system. The 28-degree roll angle of the vehicle at exit from the test installation for the G4(1S) guardrail system was only slightly higher than the 25 degrees for the G4(2W) guardrail system. The maximum roll angle of the vehicle in the test with the G4(2W) guardrail system was 39 degrees while the vehicle in the test with the G4(1S) guardrail system rolled onto its left side after exiting from the test installation. The differences could be attributed to the more severe snagging of the left front tire of the vehicle on the posts for the G4(1S) guardrail system. In fact, it appeared from review of the high-speed film that the snagging of the left front tire of the vehicle on the posts was what initiated the roll in the test with the G4(1S) guardrail system. It is expected that the steel-post G4(1S) guardrail system would have more problems with snagging on the posts because of the shallower blockout depth (6 in versus 8 in for the wood-post G4(2W) guardrail system), the shape of the steel posts, and the larger dynamic deflection.

It can be concluded from the test results that the performances of both strong-post, W-beam guardrail systems are marginal under the NCHRP Report 350 test level 3 conditions. The G4(2W) guardrail system appears to perform better than the G4(1S) guardrail system, but the vehicle did attain a maximum roll angle of 39 degrees and there was evidence of post contact in the test with the G4(2W) guardrail system. Many factors could potentially affect the performance of a guardrail system, such as variations in impact conditions (e.g., impact speed and angle), materials and construction of the test installation, and properties of the test vehicle (e.g., bumper height, length of front overhang, etc.). Accounting for all these influencing factors in a single crash test is not possible, and it is conceivable that different performance results may arise even within the range of allowable variations in one or more of these factors.

As mentioned previously, it appears that the major problem with the G4(1S) guardrail system is snagging on the posts, which can be partially attributed to the shallower blockout depth, the shape of the steel posts, and the larger dynamic deflection. There are many potential remedial measures, such as increasing the blockout depth, using a different shape for the steel posts (e.g., C-post), and/or using a heavier section for the steel posts. Further research into these and other remedial measures is recommended.

12.10.5 Thrie-Beam (G9) Guardrail System

The thrie-beam (G9) guardrail system successfully contained and redirected the vehicle. The maximum dynamic deflection of the guardrail was 1.07 m (3.5 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained extensive damage with 114 mm (4.5 in) deformation into the passenger compartment. The vehicle exited the test installation at a high roll angle and subsequently rolled two and a quarter revolutions after exiting the test installation. The exit trajectory of the vehicle was judged to have posed potential hazard to adjacent traffic as the vehicle exited the installation with an angle of approximately 35 degrees. The occupant risk factors were within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the thrie-beam (G9) guardrail system was judged to be unsatisfactory according to evaluation criteria set forth in NCHRP Report 350 because of post-impact rollover, as shown in table 39.

The unsatisfactory performance of the thrie-beam (G9) guardrail system was somewhat unexpected, particularly the violence of the rollover. The left front tire of the vehicle snagged on two posts, which could account for the high exit angle of 35 degrees. The maximum dynamic deflection of 1.07 m (3.5 ft) was higher than expected and it appeared that the deformed guardrail served as a ramp to destabilize the vehicle, as evidenced by the high roll angle of -45 degrees at exit from the guardrail system. There are some potential remedial measures, such as increasing the blockout depth, shortening the length of the blockout, eliminating the lower rail bolt, and/or using heavier section for the steel posts. Further research into these and other remedial measures is recommended.

12.10.6 Modified Thrie-Beam Guardrail System

The modified thrie-beam guardrail system successfully contained and redirected the vehicle and met all evaluation criteria set forth in NCHRP Report 350 for test level 3 conditions. The maximum dynamic deflection of the guardrail was 1.02 m (3.4 ft). There were no detached elements or debris to exhibit undue hazard to adjacent traffic. The vehicle sustained moderate damage with minimal deformation or intrusion into the passenger compartment. The vehicle remained upright and stable during and after the impact sequence. The trajectory of the vehicle was judged to have posed minimal potential hazard to adjacent traffic as the vehicle exited the installation with a trajectory of 11.1 degrees. The occupant risk factors were well within the desirable limits set forth in NCHRP Report 350. In summary, the impact performance of the modified thrie-beam guardrail system was considered satisfactory according to guidelines set forth in NCHRP Report 350, as shown in table 40.

The relatively large dynamic deflection sustained by the guardrail system and the snagging of the left wheel assembly with post 17 was somewhat unexpected given the stiffness of the thrie-beam rail element and the 457-mm- (18-in-) deep blockout. The soil condition was checked and found to be a little damp, but not to the extent that it would adversely affect the bearing capacity of the soil. Review of the high-speed film showed that posts 16 through 18 were severely twisted from the vehicle impact as the thrie-beam rail element deflected. The W6×9 steel posts are relatively weak in torsion to begin with. The added moment arm because of the deep blockout aggravated the torsional moment acting on the posts. As the posts twisted, the blockouts essentially collapsed. This in effect increased the dynamic deflection of the guardrail by 457 mm (18 in). In other words, without the collapse of the blockout, the dynamic deflection would have been 563 mm (22 in) instead of 1.02 m (3.4 ft). Also, the collapse of the blockout allowed the left front wheel assembly of the vehicle to come into direct contact with post 17, resulting in the wheel assembly being torn

Table 39. Assessment of results of test with thrie-beam (G9) guardrail system.

Test Agency: Texas Transportation Institute	Test No.: 471470-31	Test Date: 04/14/95
NCHRP 350 Evaluation Criteria	**Test Results**	**Assessment**
<u>Structural Adequacy</u> A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle. The vehicle did not penetrate or go over the installation.	Pass
<u>Occupant Risk</u> D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to pose any undue hazard to adjacent traffic. There was 114 mm (4.5 in) deformation downward from the roof into the occupant compartment over the passenger side because of post-impact rollover.	Fail
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during the impact with the guardrail; however, as the vehicle exited from the test installation, it had attained a roll angle of -45 degrees. The vehicle subsequently rolled over two and a quarter revolutions after exiting the guardrail and came to rest on its left side.	Fail
<u>Vehicle Trajectory</u> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle showed potential for intrusion into adjacent traffic lanes.	Fail
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 8.0 m/s Longitudinal Ridedown Acceleration = -7.0 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 35 degrees, which was more than 60 percent of the test impact angle.	Fail

Table 40. Assessment of results of test with modified thrie-beam guardrail system.

Test Agency: Texas Transportation Institute | Test No.: 471470-30 | Test Date: 01/11/95

NCHRP 350 Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The guardrail contained and redirected the vehicle through controlled lateral deflection. The vehicle did not penetrate or go over the installation.	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	There were no detached elements or debris to pose any undue hazard to adjacent traffic. There was minimal deformation into the occupant compartment that was not considered life-threatening.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and relatively stable during and after the collision.	Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 7.8 m/s Longitudinal Ridedown Acceleration = -9.7 g's.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle at loss of contact was approximately 11.1 degrees which was less than 60 percent of the test impact angle of 25.1 degrees.	Pass

off the vehicle. However, even with the wheel snagging on the post, the modified thrie-beam guardrail system successfully contained and redirected the vehicle with no indication of vehicle instability or unacceptable occupant risk factors.

XIII. MELT

The Modified Eccentric Loader Terminal (MELT) is one of the end terminals currently approved for use with W-beam guardrail systems. The MELT has successfully met all evaluation criteria set forth in NCHRP Report 230. However, with the adoption of NCHRP Report 350 by the FHWA as the official guidelines for crash testing of roadside safety features, it became necessary to retest the MELT to the new guidelines. Specifically, one of the design test vehicles specified in NCHRP Report 230, the 2044-kg (4500-lb) passenger car was replaced by a 2000-kg (4409-lb) 3/4-ton pickup truck (2000P) under NCHRP Report 350 guidelines. The MELT has not been crash tested with the 2000P test vehicle. The crash tests presented in this chapter are part of the effort to evaluate the MELT with the 2000P test vehicle according to NCHRP Report 350 guidelines.

13.1 TEST INSTALLATION

The test installation consisted of 30.5 m (100 ft) of the wood strong-post, W-beam (G4(2W)) guardrail system with a MELT installed at both ends, for a total installation length of 53.3 m (175 ft). The layout of the test installation is shown in figure 87, and photographs of the test installation are shown in figure 88. Note that both the length-of-need guardrail section and the two MELTs are constructed to metric specifications.

The standard G4(2W) guardrail system consisted of 1625-mm- (5-ft, 4-in-) long, 152-mm × 203-mm (6-in × 8-in) wood posts with 356-mm- (14-in-) long, 152-mm × 203-mm (6-in × 8-in) wood blockouts, spaced 1905 mm (6 ft, 3 in) on center, and 3810-mm- (12-ft, 6-in-) long 12-gauge W-beam rail elements. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers.

Figure 89 shows construction details for the MELT as constructed and crash tested. Photographs of the terminal are shown in figure 90. The MELT had a total length of 11.4 m (37 ft, 6 in), consisting of two 1905-mm (6-ft, 3-in) spans at the end of the terminal, followed by three 1270-mm (4-ft, 2-in) spans, and then two 1.9-m (6-ft, 3-in) spans. This transitioned into the standard G4(2W) guardrail system. The height to the center of the W-beam rail element in the terminal section was 550 mm (21.7 in). The end of the terminal was flared 1220 mm (4 ft) from the length-of-need or tangent section of the guardrail and the parabolic flare was effected over the first 11.4 m (37 ft, 6 in), with offsets of 1220, 635, 355, 200, 100, 65, and 25 mm (4.0, 2.08, 1.16, 0.66, 0.33, 0.21, and 0.08 ft) for posts 1 through 7, respectively. Note that the first 3810-mm (12-ft, 6-in) section of the W-beam rail element for the end terminal was shop curved to a radius of 11.6 m (38 ft) to accommodate the parabolic curve..

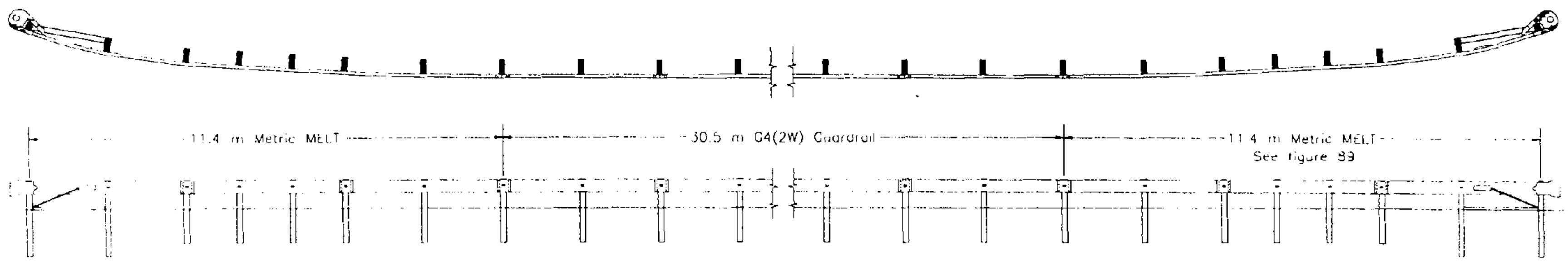


Figure 87. Layout of the metric MELT installation used in testing.

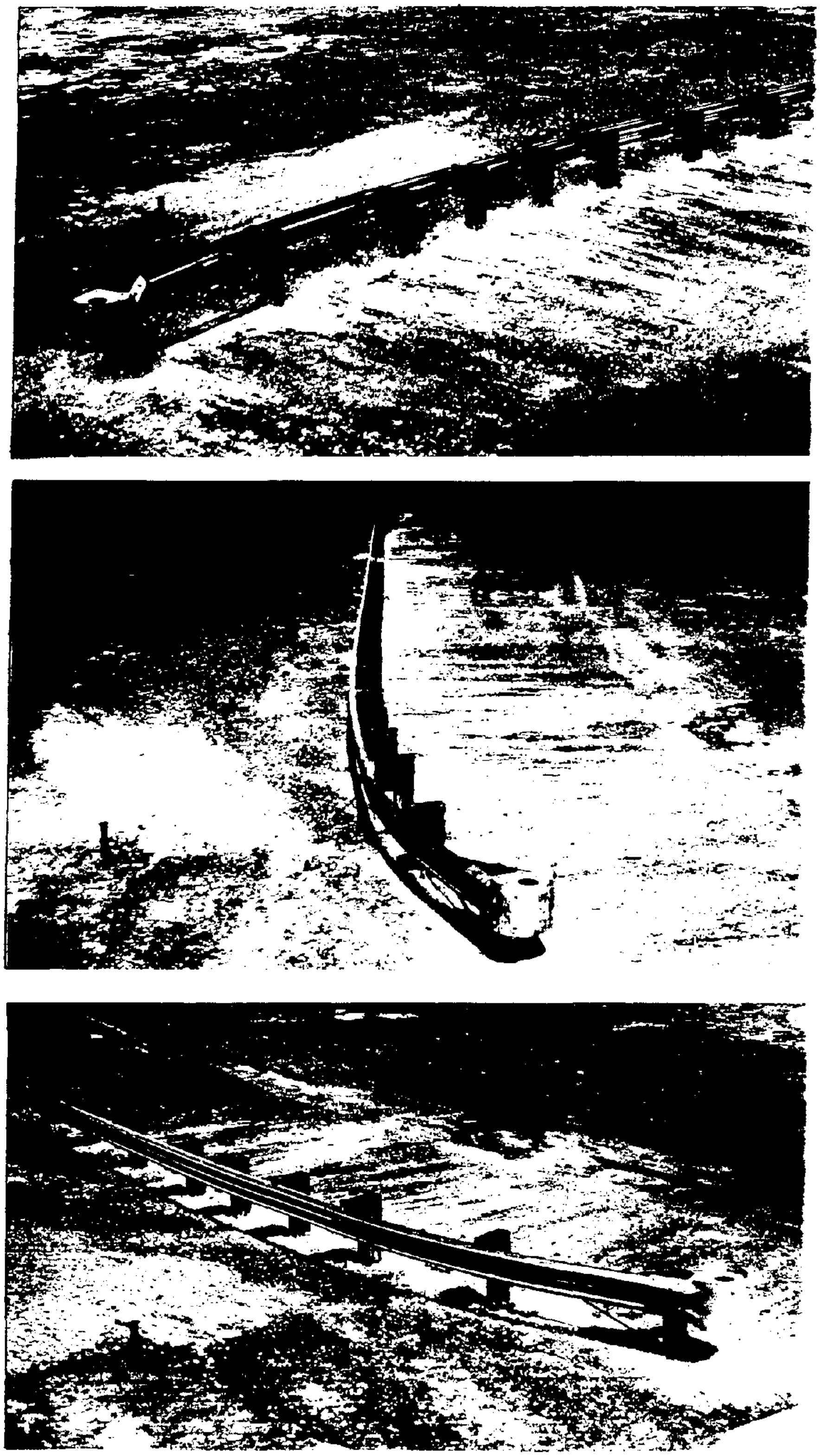


Figure 88. Photographs of the metric MELT test installation.

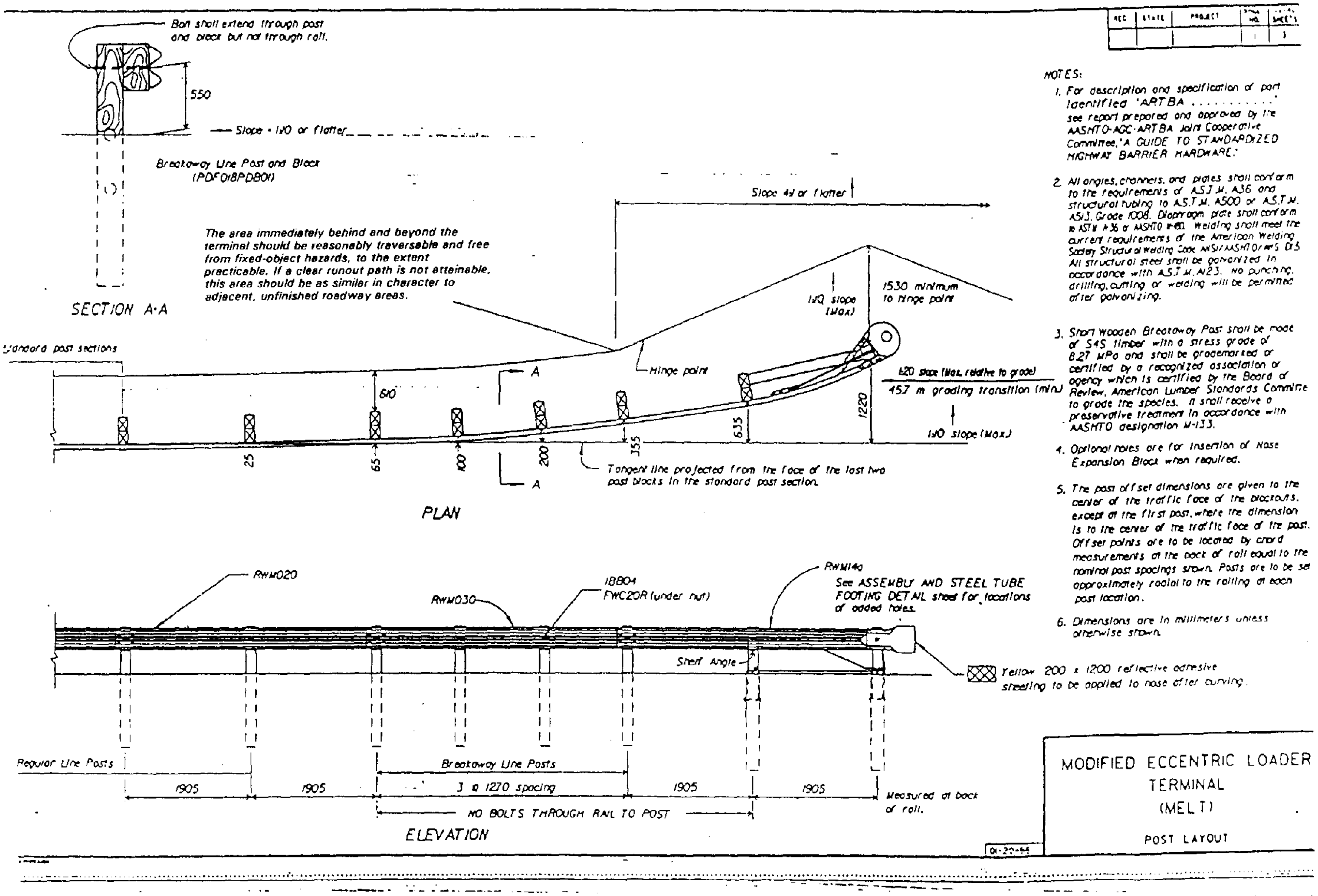


Figure 89. Details of the metric MELT used for testing.

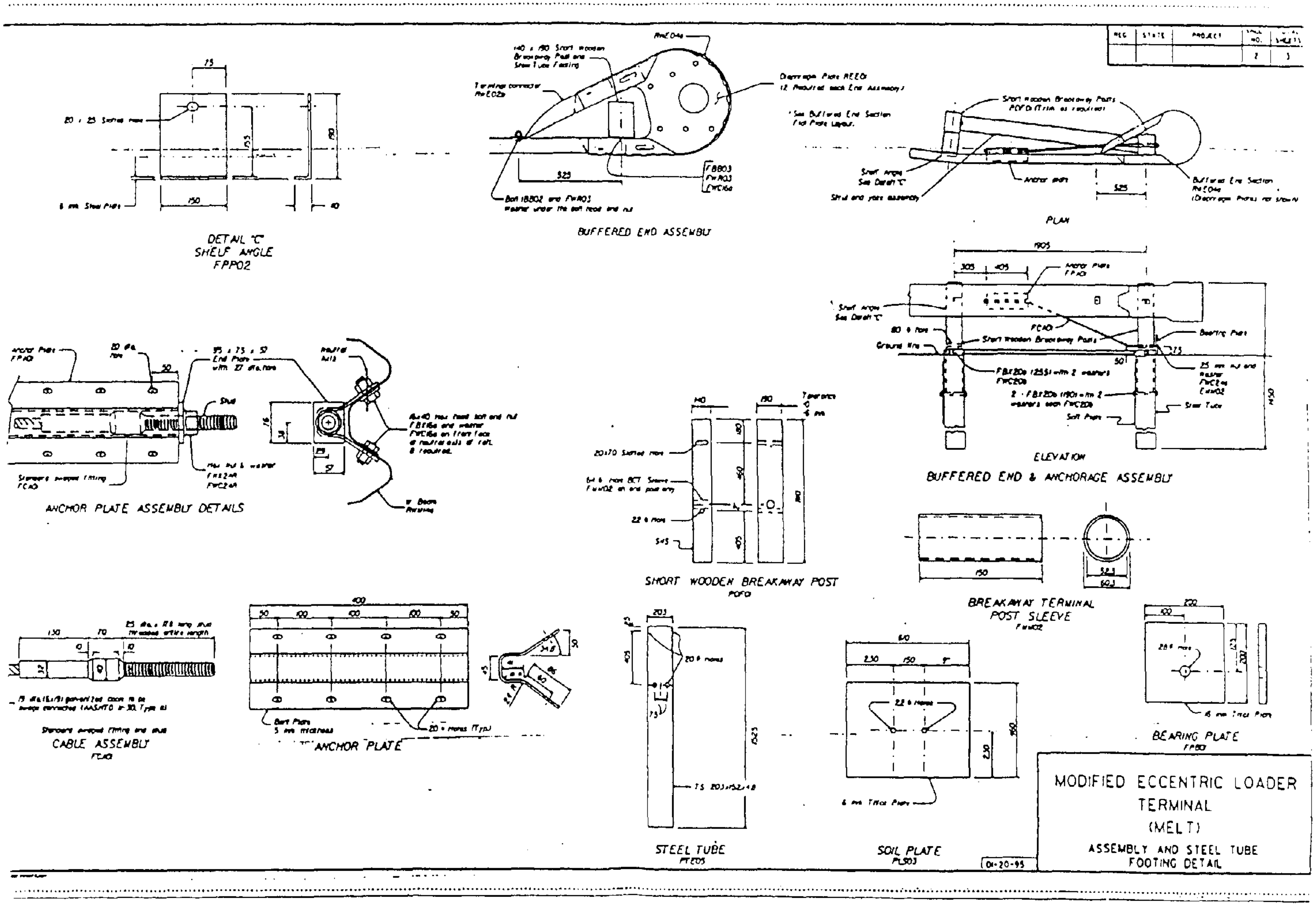


Figure 89. Details of the metric MELT used for testing (continued).

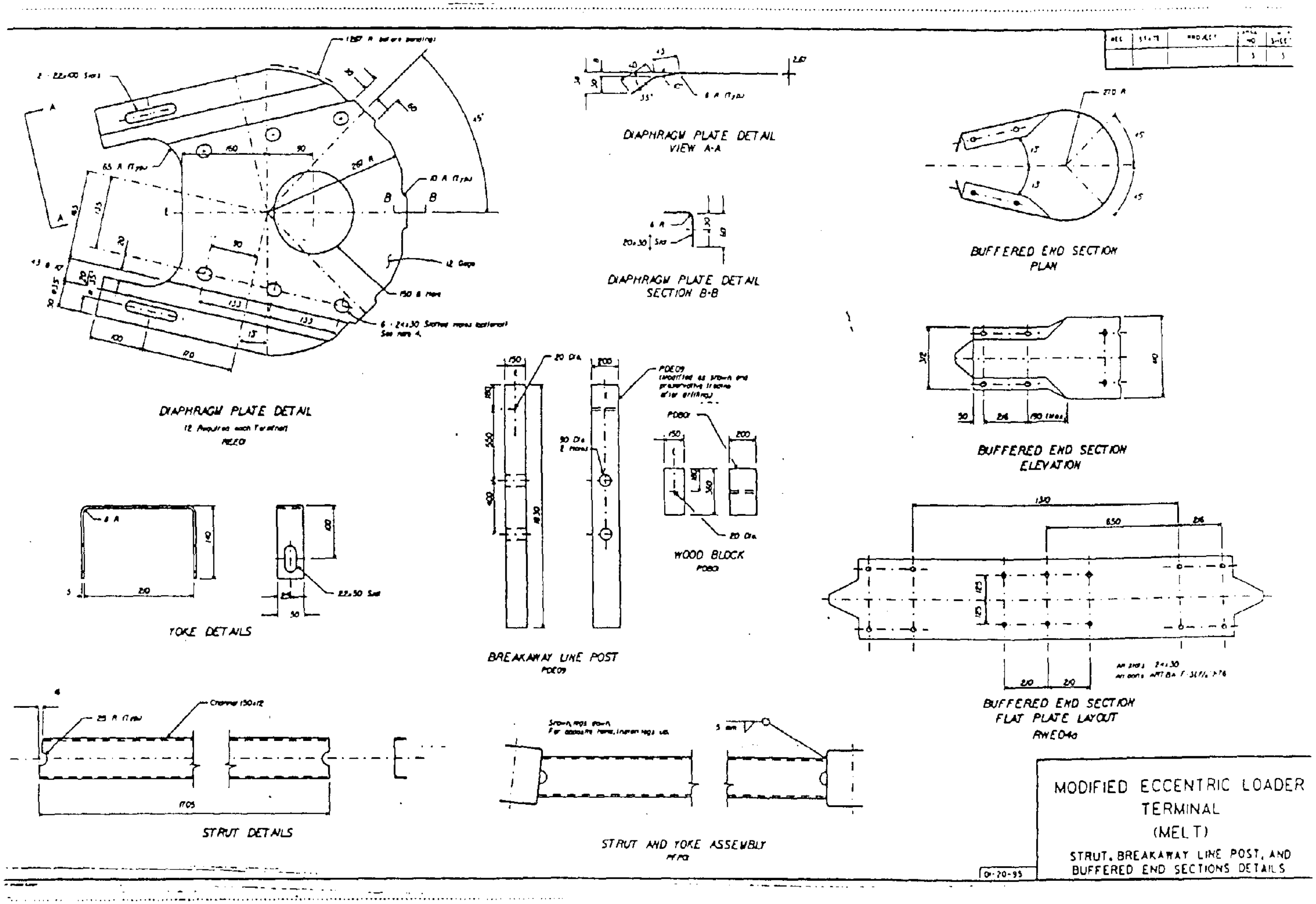


Figure 89. Details of the metric MELT used for testing (continued).

Figure 90. Photographs of the metric MELT.

The buffered nose piece had two bolted-on diaphragms. Posts 1 and 2 were breakaway wooden posts installed in 1525-mm- (5-ft-) long, TS 152-mm × 203-mm × 4.8-mm (TS 6-in × 8-in × 3/16-in) steel foundation tubes with 460-mm × 610-mm × 6-mm (18-in × 24-in × 1/4-in) soil plates. A 160-mm × 50-mm (6-in × 2-in) channel strut connected the two foundation tubes at ground level for increased anchorage capacity. The posts were 1110 mm (43 in) long with cross-sectional dimensions of 140 mm × 190 mm (5-1/2 in × 7-1/2 in). A 64-mm- (2-1/2-in-) diameter hole was drilled through these posts at ground level to facilitate breaking of the posts upon impact. The post bolt hole of the end post (i.e., post 1) was slotted with the dimensions of 20 mm × 70 mm (3/4 in × 2-3/4 in). The second post (post 2) was not bolted to the W-beam rail element, but rested on a shelf angle attached to the post. Photographs showing the details for posts 1 and 2 are shown in figure 91.

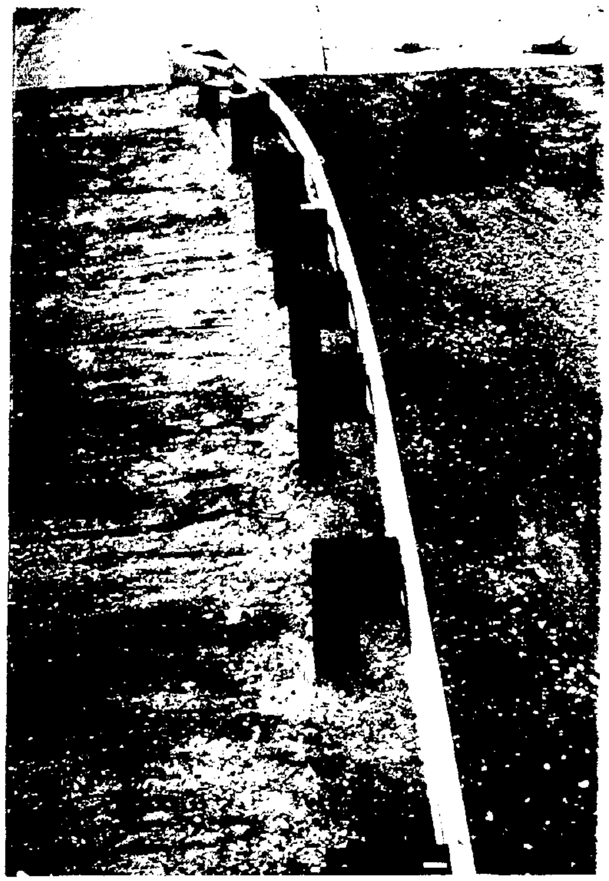
Posts 3 through 6 in the terminal section were 1830-mm- (6-ft-) long wooden breakaway line posts or CRT posts, and the W-beam rail element was not bolted onto these posts. In other words, the W-beam rail element was bolted at the end post (post 1) and then the next bolted post was post 7, for an unsupported rail length of 9.5 m (31 ft, 3 in). However, it should be noted that the rail element was supported by a shelf angle at the second post (post 2). Standard wooden line posts were then used starting at post 7 with the standard 1905-mm (6-ft, 3-in) spacing. Photographs showing the details at posts 1 through 8 are shown in figure 92.

13.2 TEST NUMBER 471470-32 (NCHRP REPORT 350 TEST DESIGNATION 3-35)

Test vehicle: 1989 GMC 2500 Pickup	Impact speed: 100.5 km/h (62.4 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 20.6 degrees
Gross static weight: 2076 kg (4577 lb)	

The vehicle impacted the terminal 421 mm (16.6 in) upstream left of post 3. Upon impact, the W-beam rail element began to deform and post 3 started to be displaced laterally. Post 4 fractured at ground level, and vehicle redirection occurred shortly afterwards. Posts 5 and 6 fractured at ground level, the right wheels of the vehicle rode over debris of post 6, and the vehicle pitched upward. The entire right side of the vehicle made contact with the W-beam rail element. The vehicle became parallel with the installation traveling at 78.7 km/h (48.9 mi/h). The right front tire contacted post 7 (the first standard line post), and snagged at the post causing the vehicle to bow upward through the middle of the body. The maximum dynamic deflection of the metal rail element of 1.2 m (4.0 ft) occurred near post 7. The right front tire contacted post 8 and the rear of the vehicle continued to pitch upward. The right rear tire rode up on top of the W-beam rail element. The vehicle lost contact with the installation traveling at a speed of 74.8 km/h (46.5 mi/h) and at an exit angle of 12.5 degrees. As the vehicle exited the rail, it was completely airborne. The front of the vehicle came back down and impacted the ground at a -26 degree pitch angle. The vehicle began to rotate clockwise at a high yaw rate. The left side tires then contacted the ground with the vehicle oriented almost 90 degrees to the installation and the vehicle began to roll counterclockwise. The vehicle subsequently rolled 360 degrees and came to rest on its wheels 32 m (106 ft)

Figure 91. Photographs of metric MELT posts 1 and 2.



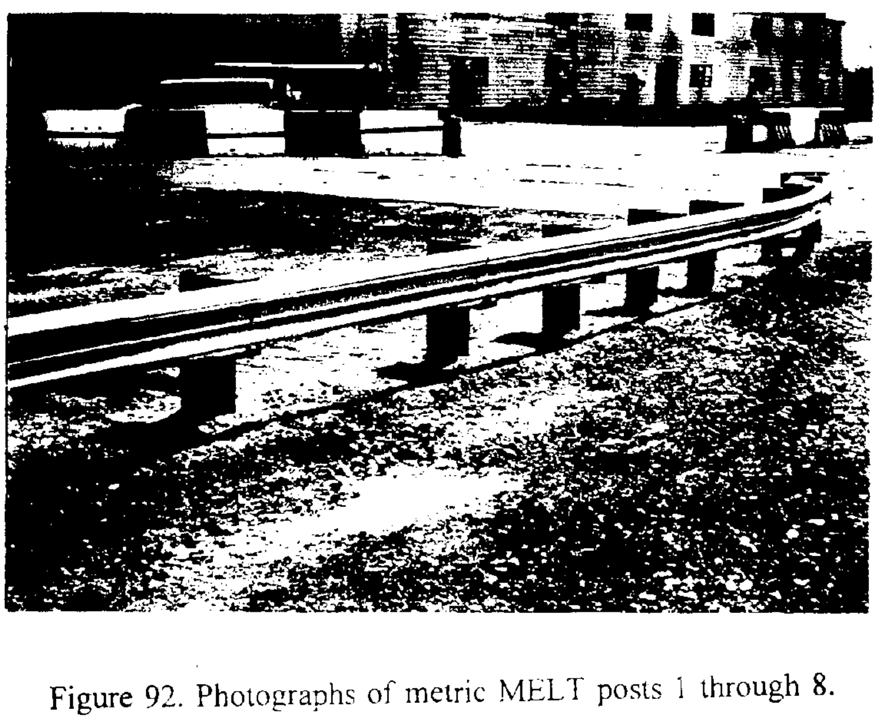


Figure 92. Photographs of metric MELT posts 1 through 8.

downstream and 3.3 m (11 ft) forward of the initial point of impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 93.

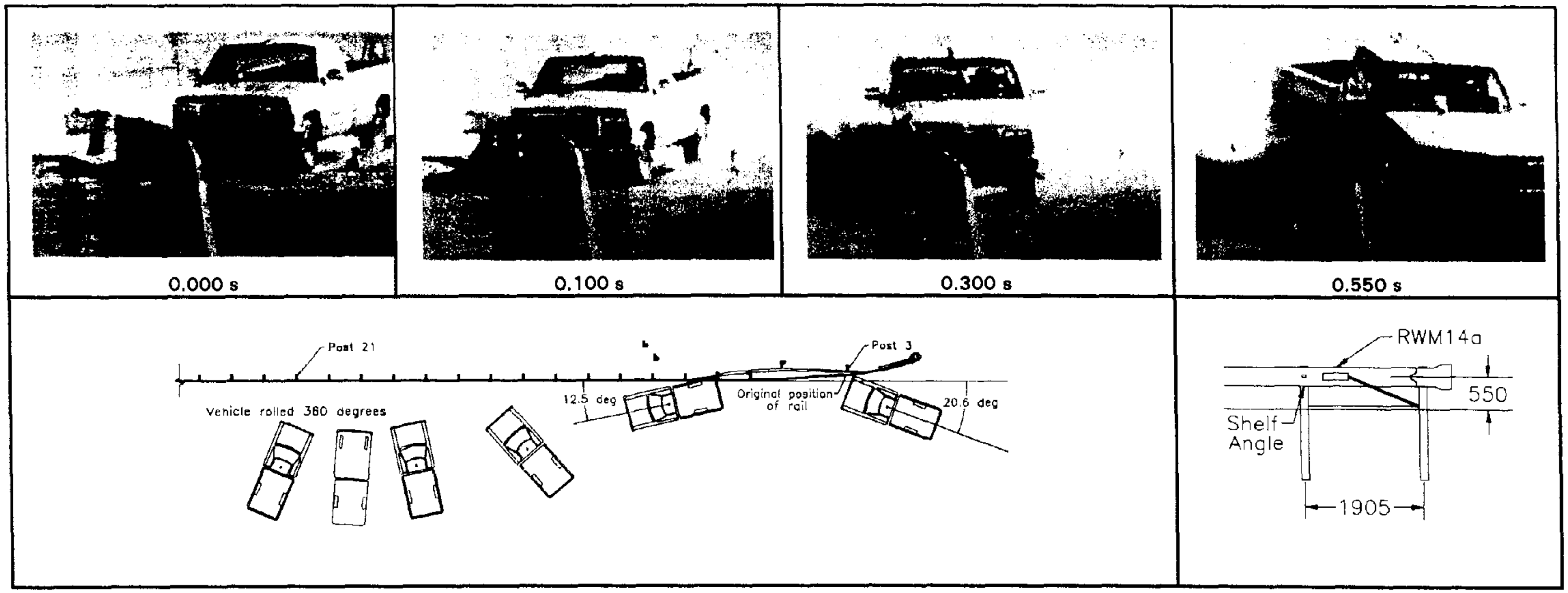
The W-beam rail element was deformed between posts 3 and 9. The foundation tube for post 1 (end post) was displaced 44 mm (1.75 in) toward the point of impact. Posts 4, 5, and 6 fractured at ground level and were thrown behind the installation. Lateral deflection occurred at posts 2 through 9. The post bolt tore through the W-beam rail element at post 7 and the post and blockout were twisted. Maximum dynamic deflection of the W-beam rail element during the test was 1.2 m (4.0 ft) near post 7. Maximum permanent deformation of the W-beam rail element was 0.7 m (2.3 ft), also at post 7. The vehicle was in contact with the terminal section for a length of 7.5 m (24.8 ft).

The vehicle's right side A-arm, tie rods, spindle, shocks, and frame were damaged. The right front tire was cut, the right rear tire was partially aired out, and both rims were bent. There was buckling in the floor pan area and in the frame between the cab and bed. The front bumper, grill, hood, left and right front quarter panels, right door, right rear quarter panel, and rear bumper were also damaged. Maximum exterior crush at the right front corner of the vehicle was 430 mm (16.9 in) at bumper height. Maximum crush in the right side floor pan area was 51 mm (2.0 in). Damage to the vehicle because of rollover included the roof, windshield, and left side of the vehicle. Maximum occupant compartment deformation was 171 mm (6.7 in) on the right side of the roof.

13.3 TEST NUMBER 471470-34 (NCHRP REPORT 350 TEST DESIGNATION 3-31)

Test vehicle: 1989 Chevrolet 2500 Pickup Test inertia weight: 2000 kg (4409 lb) Gross static weight: 2076 kg (4577 lb)	Impact speed: 100.7 km/h (62.6 mi/h) Impact angle: 0 degrees

The vehicle impacted the nose of the terminal 2 mm (0.08 in) left of post 1. Upon impact, the W-beam rail element began to flex, twist, and move away from posts 2 and 3. The vehicle contacted the first post and the bumper was pushed into the right front tire. The W-beam rail element began to move away from post 4 and the vehicle began to yaw in a clockwise direction. The W-beam rail element began to buckle at the post 3 location (first buckle). The W-beam rail element began to pull away from posts 5 and 6. The nose of the terminal made contact with post 2 and then the vehicle contacted the post. The nose of the terminal made contact with post 3 and the left front corner of the bumper of the vehicle made contact with the nose of the terminal and post 3. The W-beam rail element began to buckle midspan between posts 4 and 5 (second buckle) and the nose of the terminal contacted post 4. The elbow formed by the first buckle of the W-beam rail element contacted the left door of the vehicle. The vehicle lost contact with the installation traveling at a speed of 84.8 km/h (52.7 mi/h) and at an exit angle of 9.9 degrees behind the installation. Maximum extension of the elbow of the second buckle was 3.3 m (10.8 ft) toward the traffic side of the guardrail.



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-32
Date	02/23/95
Test Article	
Type	Terminal
Name or Manufacturer	Metric MELT
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Metric MELT on G4(2W) Guardrail
Soil Type and Condition	Strong Soil, Damp
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 GMC 2500 Pickup
Mass (kg) Curb	1903 (4192 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	100.5 (62.4 mi/h)
Angle (deg)	20.6
Exit Conditions	
Speed (km/h)	74.8 (46.5 mi/h)
Angle (deg)	12.5
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.9 (16.1 ft/s)
y-direction	4.3 (14.2 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.8
y-direction	-24.1
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-3.4
y-direction	-7.3
z-direction	-4.2

Test Article Deflections (m)	
Dynamic	1.2 (4.0 ft)
Permanent	0.7 (2.3 ft)
Vehicle Damage	
Exterior	
VDS	01RFQ5 & 09L&T4
CDC	01RFEK & 60TYGO3
Interior	
OCDI	AS0200000
Maximum Exterior Vehicle Crush (mm)	430 (16.9 in)
Max. Occ. Compart. Deformation (mm)	171 (6.7 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	-360
Max. Pitch Angle (deg)	-26
Max. Yaw Angle (deg)	74

Figure 93. Summary of results for test 471470-32.

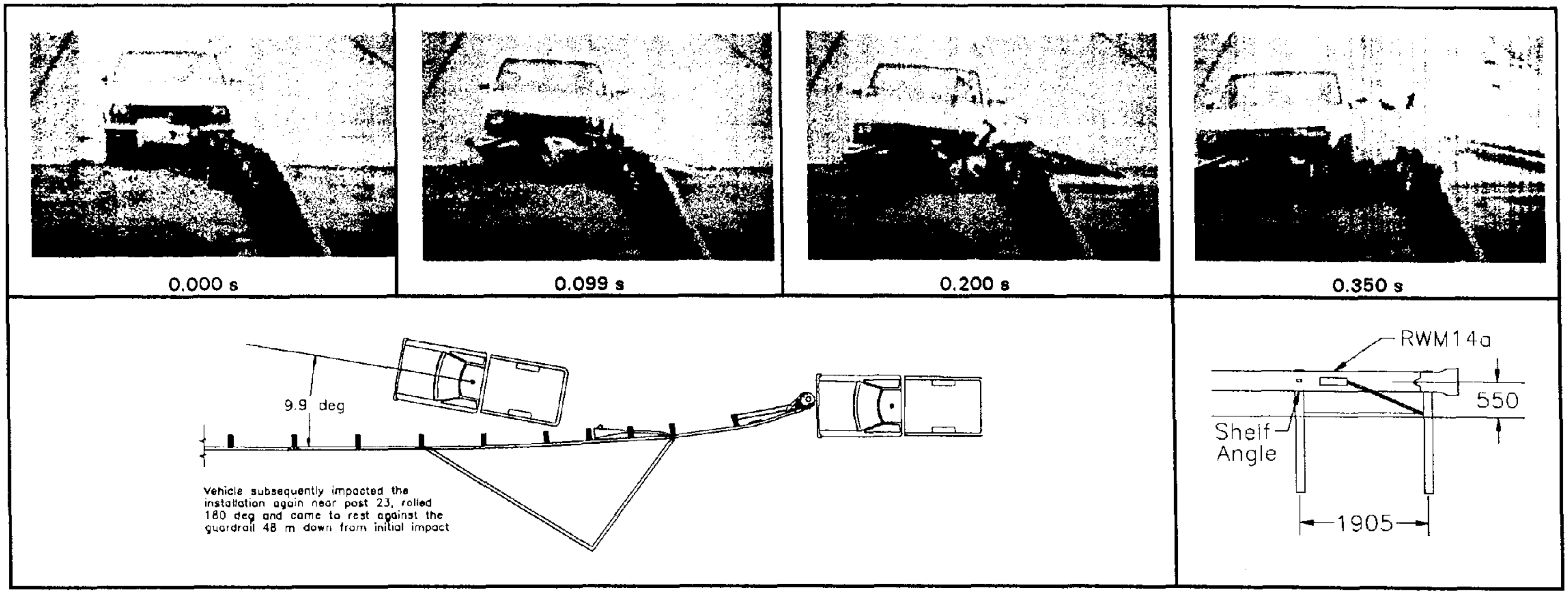
After the vehicle exited the installation, the damage sustained by the left corner of the front bumper restricted the rotation of the left front tire and caused the front wheels to turn sharply to the left. Consequently, the vehicle turned abruptly to the left toward the backside of the guardrail installation and began to yaw rapidly in a counterclockwise direction. The vehicle was skidding sideways when it subsequently impacted the backside of the guardrail installation near post 23 or approximately 40 m (131 ft) downstream from the nose of the terminal. Upon impact with the guardrail installation, the vehicle began to roll to its right and subsequently rolled 180 degrees, impacting posts 23 and 24 in the process. The vehicle came to rest on its roof on top of the guardrail approximately 48 m (158 ft) downstream of the initial point of impact. Note that the brakes were not applied until after the secondary impact. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 94.

The W-beam rail element was deformed from posts 1 through 8 and extended 3.2 m (10.5 ft) toward traffic. The foundation tube for post 2 was displaced 32 mm (1.25 in). Posts 1 through 4 fractured at ground level and came to rest just behind the installation (maximum distance of 1.2 m (4.0 ft)). There were marks on the rear of posts 5 and 6 where the end terminal was pushed into them as the vehicle passed behind the installation. The test installation sustained minor damage from the secondary impact. Post 23 was fractured near ground level and posts 24 and 25 were displaced. The W-beam rail element was deformed in the vicinity of these posts. Note that the W-beam rail was lying on the ground since post 24 was the first standard strength post for the downstream MELT and the W-beam rail element was not connected to posts 25 through 29.

The vehicle sustained moderate damage from the initial impact prior to the rollover from the secondary impact. The frame, steering box, and pitman arm were damaged. The front bumper was pushed rearward into the tires and wheel assembly. There was slight buckling in the floor pan area on the left side. The front bumper, grill, hood, left and right front quarter panels, left door, left rear quarter panel, and rear bumper also were damaged. Maximum exterior crush at the center front of the vehicle was 440 mm (17.3 in) at bumper height. Maximum crush in the left side floor pan area was 9 mm (0.4 in). All other damage to the vehicle occurred after the vehicle rolled. Damage to the vehicle because of rollover included the roof, windshield, and right side of the vehicle. Maximum occupant compartment deformation was 400 mm (15.7 in) downward from the roof on the driver's side.

13.4 SUMMARY OF FINDINGS

In the length-of-need strength test (test no. 471470-32), the MELT successfully contained and redirected the vehicle. However, the right front wheel assembly of the vehicle snagged on post 7 (the first standard line post), causing the vehicle to yaw and pitch significantly and subsequently to roll 360 degrees. The test installation sustained moderate damage. The vehicle sustained moderate damage from impact with the terminal. The subsequent rollover resulted in additional damage to the vehicle with some intrusion into the roof area of the occupant compartment. The exit trajectory of the vehicle was judged to



General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-34
Date	03/28/95
Test Article	
Type	Terminal
Name or Manufacturer	Metric MELT
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Metric MELT on G4(2W) Guardrail
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1989 Chevrolet 2500
Mass (kg) Curb	1893 (4170 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	100.7 (62.6 mi/h)
Angle (deg)	0 - End-on
Exit Conditions	
Speed (km/h)	84.8 (52.7 mi/h)
Angle (deg)	9.9 Behind the Rail
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	4.4 (14.3 ft/s)
y-direction	2.5 (8.3 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	-4.8
y-direction	6.4
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-5.8
y-direction	2.6
z-direction	1.9

Test Article Deflections (m)	
Dynamic	3.3 (10.8 ft)
Permanent	3.2 (10.5 ft)
Vehicle Damage	
Exterior	
VDS	12FC3 & 03R&T6
CDC	12FCEK2 & 00TDDO5
Interior	
OCDI	FS0400000
Maximum Exterior Vehicle Crush (mm)	440 (17.3 in)
Max. Occ. Compart. Deformation (mm)	400 (15.7 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	180
Max. Pitch Angle (deg)	-6
Max. Yaw Angle (deg)	-87

Figure 94. Summary of results for test 471470-34.

have posed minimal potential hazard to adjacent traffic as the vehicle came to rest 3.3 m (11 ft) in front of the installation. The exit angle at loss of contact of 12.5 degrees was considered marginal, as the preferred limit for this test was 12.4 degrees (60 percent of the impact angle). Although not part of the evaluation criteria, the highest 0.010-s ridedown acceleration in the lateral direction was 24.1 g's, which exceeded the limit of 20 g's set forth in NCHRP Report 350. This high lateral ridedown acceleration occurred shortly after the right front wheel assembly snagged at post 7. The other occupant risk factors were well within the desirable limits set forth in NCHRP Report 350.

In the end-on test (test no. 471470-34), the MELT gated as designed, allowing the vehicle to penetrate behind the guardrail installation in a controlled manner. There were no detached elements or debris from the test article that penetrated or showed the potential for penetrating the occupant compartment, or presented undue hazard to adjacent traffic. Posts 1 through 4 fractured at ground level, but remained near the installation. There was minimal deformation or intrusion into the occupant compartment. The left side of the floor pan area was deformed 9 mm (0.4 in), which was not considered of any serious consequence. The vehicle remained upright and stable during the collision and upon loss of contact for the initial impact. However, after the vehicle penetrated behind the test installation and exited from the initial impact with the terminal, it turned back toward the back side of the test installation because of interactions between the damaged front bumper and the left front wheel assembly. The vehicle subsequently impacted the backside of the test installation in a secondary collision, resulting in the vehicle rolling 180 degrees to its right and coming to rest on its roof. The rollover resulted in extensive damage to the vehicle with significant intrusion into the roof area of the occupant compartment.

The performance of the MELT for the initial impact was judged to be satisfactory, but the post-impact trajectory of the vehicle was not considered acceptable because of rollover after the secondary impact. It could be argued that the interactions between the damaged front bumper and the left front wheel assembly might be a rare occurrence. Another argument is that the terrain behind the guardrail in a typical field installation is usually not flat and level as with the test installation, and there would be a slope or embankment behind the guardrail that would have reduced the probability of the vehicle turning back toward and impacting the backside of the installation. On the other hand, the front bumper will likely be damaged in any end-on impact with the terminal, and the interaction between the damaged bumper and the front wheel assemblies is highly unpredictable. Also, there are installations where the terrain behind the guardrail is relatively level and flat, such as those shielding bridge piers and other fixed hazards.

In summary, the impact performance of the MELT is judged to be unsatisfactory according to evaluation criteria set forth in NCHRP Report 350 in both tests, as shown in tables 41 and 42. In the length-of-need strength test, the vehicle snagged on a post and subsequently rolled over after exiting from the test installation. In the end-on test, the MELT performed satisfactorily in the initial impact, but the post-impact trajectory of the vehicle was not considered acceptable because of rollover after a secondary impact with the rear of the guardrail.

Table 41. Assessment of results of test 471470-32 (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute — Test No.: 471470-32 — Test Date: 02/23/95

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The test article contained and redirected the vehicle. The vehicle did not penetrate the installation. Maximum lateral deflection of the W-beam was 1.2 m (4.0 ft).	Pass
Occupant Risk		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Posts 4, 5, and 6 broke off at ground level, and were thrown behind the installation (maximum distance of 4.6 m (15.0 ft)). Maximum deformation of 171 mm (6.7 in) occurred in the roof area because of rollover and a maximum of 22 mm (0.9 in) was measured in the floorpan area.	Fail
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during the collision; however, it rolled 360 degrees after exiting the installation. Wheel snagging at post 7 imparted significant yaw and pitch to the vehicle, causing the vehicle to subsequently roll over.	Fail
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 4.9 m/s (16.1 ft/s) Longitudinal Ridedown Acceleration = -4.8 g's	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Preferably, the exit angle should be less than 12.4 degrees (60 percent of 20.6 degrees). The exit angle at loss of contact with the test article was 12.5 degrees.	Marginal

Table 42. Assessment of results of test 471470-34 (according to NCHRP Report 350).

Test Agency: Texas Transportation Institute | Test No.: 471470-34 | Test Date: 03/28/95

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The metric MELT gated as designed, allowing the vehicle to penetrate behind the guardrail installation in a controlled manner.	Pass
<u>Occupant Risk</u>		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Posts 1 through 4 fractured at ground level, but remained near their original locations (maximum distance of 1.2 m (4.0 ft)). Maximum deformation to the floorpan area of 9 mm (0.4 in) was <u>not</u> considered serious. Deformation to the roof was due to a secondary impact into the backside of the installation.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during the collision and upon loss of contact. However, the vehicle impacted the backside of the installation in a secondary impact and rolled 180 degrees onto its roof.	Fail
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12 Longitudinal / 3 / 5	Longitudinal Occupant Impact Velocity = 4.4 m/s Laeral Occupant Impact Velocity = 2.5 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Longitudinal Occupant Ridedown Acceleration = -4.8 g's Lateral Occupant Ridedown Acceleration = 2.6 g's	Pass
<u>Vehicle Trajectory</u>		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was no intrusion into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle penetrated behind the guardrail installation in a controlled manner.	Pass

XIV. MODIFIED MELT

As discussed in the previous chapter, the MELT was tested with the 2000P test vehicle in two tests, one a redirection test at the beginning of length of need (test no. 471470-32) and the other an end-on test (test nos. 471470-34). The MELT failed to perform satisfactorily in both tests. In the redirection test at the beginning of length of need (test no. 471470-32), the vehicle was contained and redirected by the terminal, but the right front tire of the vehicle snagged on the first standard wooden post (post 7) and subsequently rolled over. For the end-on test (test no. 471470-34), the terminal gated and allowed the vehicle to proceed behind the guardrail as designed. However, the vehicle then steered back and impacted the rear of the guardrail because of damage sustained by the left front wheel assembly, resulting in rollover of the vehicle.

As a result of these two failed crash tests, FHWA redesigned the MELT and the redesigned terminal (hereinafter referred to as the modified MELT) was then crash tested to evaluate its safety performance in accordance with NCHRP Report 350 guidelines. This chapter presents the results of two crash tests conducted on this modified MELT. The first test (test no. 471470-35) involved a 2000-kg (4409-lb) pickup truck impacting the terminal end-on with the center of the vehicle aligned with the center of the end post at a nominal speed of 100 km/h (62.2 mi/h). The second test (test no. 471470-36) involved a 2000-kg (4409-lb) pickup truck impacting the terminal at the beginning of length of need at a nominal speed of 100 km/h (62.2 mi/h) and at an angle of 20 degrees relative to the tangent section.

14.1 TEST INSTALLATION

The test installation consisted of 30.5 m (100 ft) of the wood strong-post, W-beam (G4(2W)) guardrail system with a modified MELT installed at both ends, for a total installation length of 53.3 m (175 ft). A schematic of the test installation is shown in figure 95 and photographs of the test installation are shown in figure 96. Note that both the length-of-need guardrail section and the two modified MELTs are constructed to metric specifications.

The standard G4(2W) guardrail system consisted of 1829-mm- (6-ft-) long, 152 mm × 203 mm (6 in × 8 in) wood posts with 356-mm- (14-in-) long, 152 mm × 203 mm (6 in × 8 in) wood blockouts, spaced 1905 mm (6 ft, 3 in) on center, and 3810-mm- (12-ft, 6-in-) long 12-gauge W-beam rail sections. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in). The W-beam rail elements were attached to the posts with 15.9-mm- (5/8-in-) diameter carriage bolts without any washers.

Figure 97 shows a schematic of the modified MELT as constructed and tested. Photographs of the terminal are shown in figure 98. The modified MELT had a total length of 11.4 m (37 ft, 6 in), consisting of two 1905-mm (6-ft, 3-in) spans at the end of the

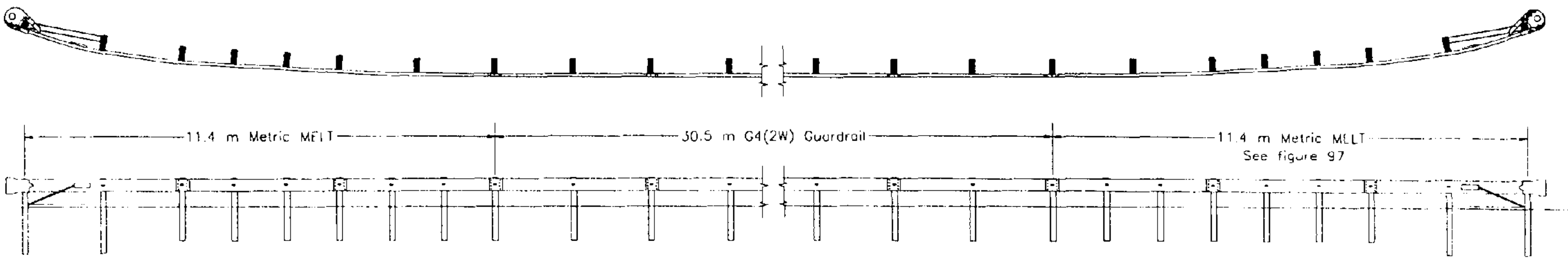
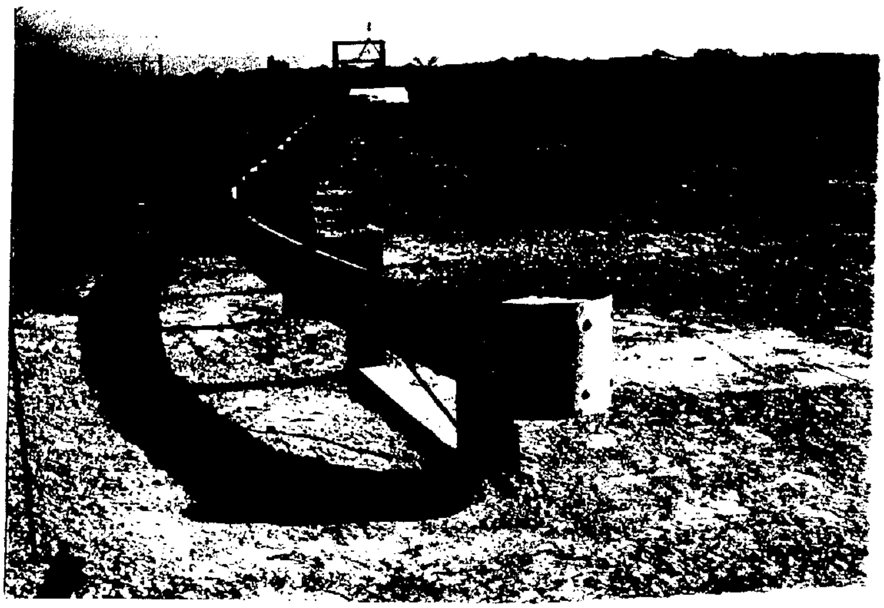


Figure 95. Details of modified MELT installation used in tests 471470-35 and 36.



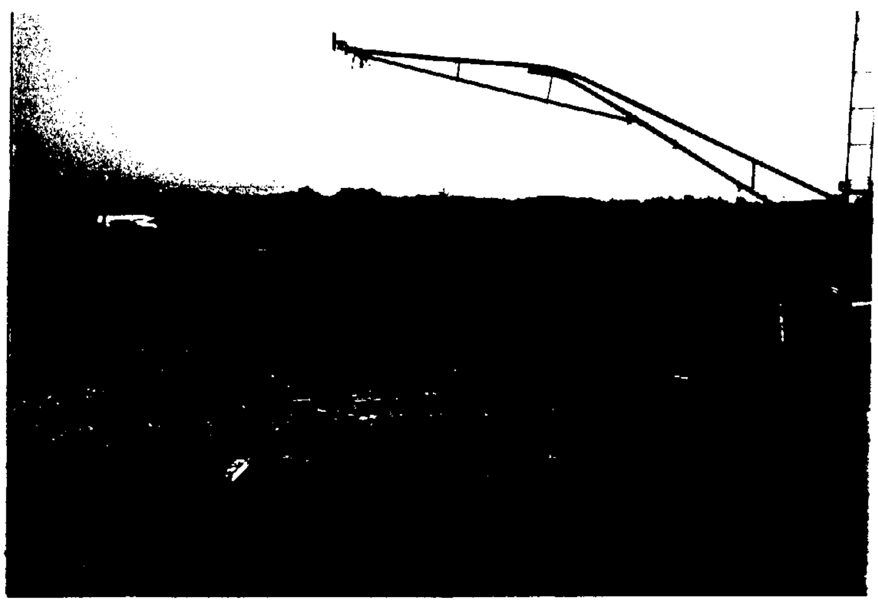


Figure 96. Modified MELT used for tests 471470-35 and 36.

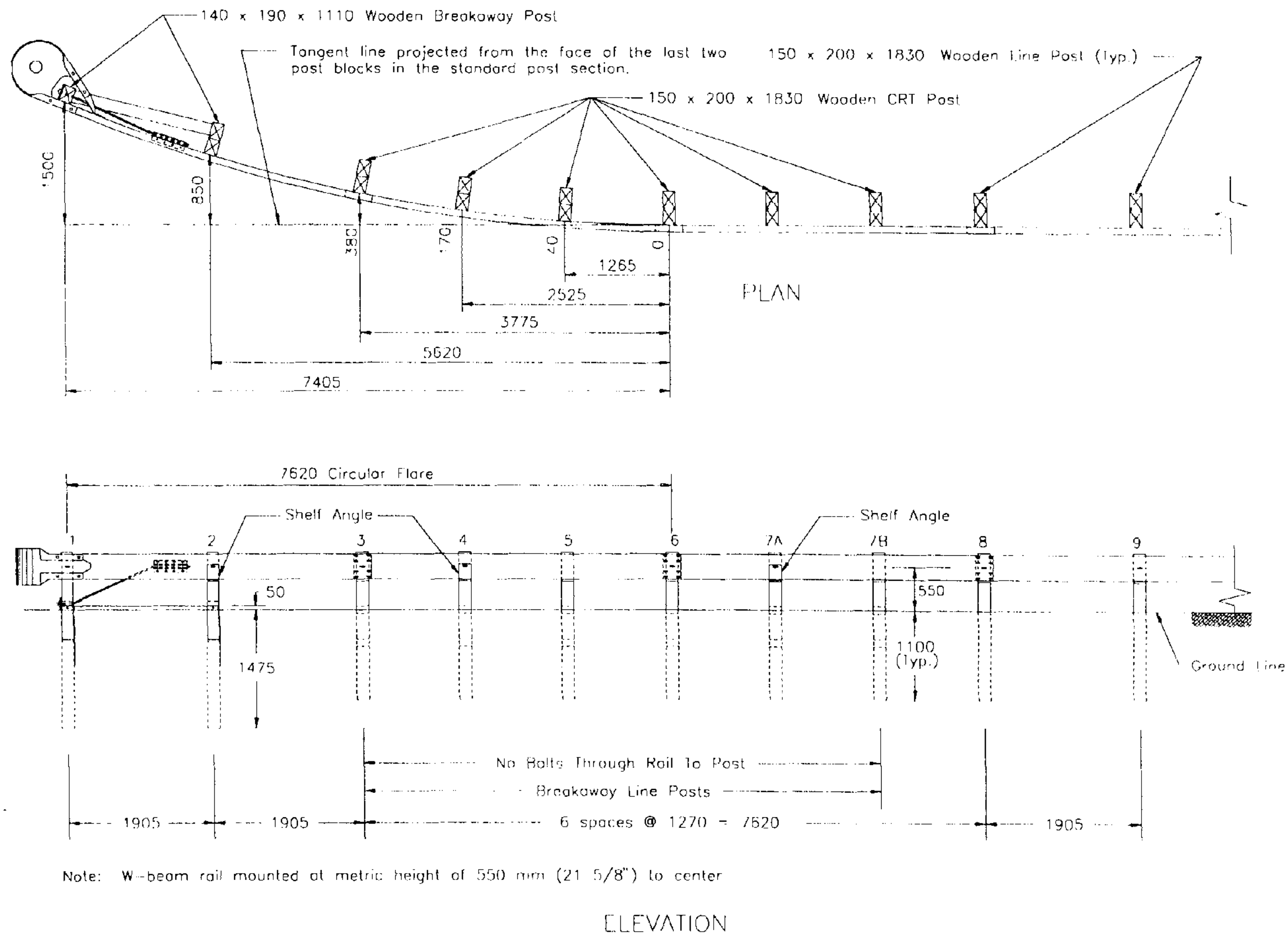


Figure 97. Details of modified MELT used in test 471470-35 and 36.

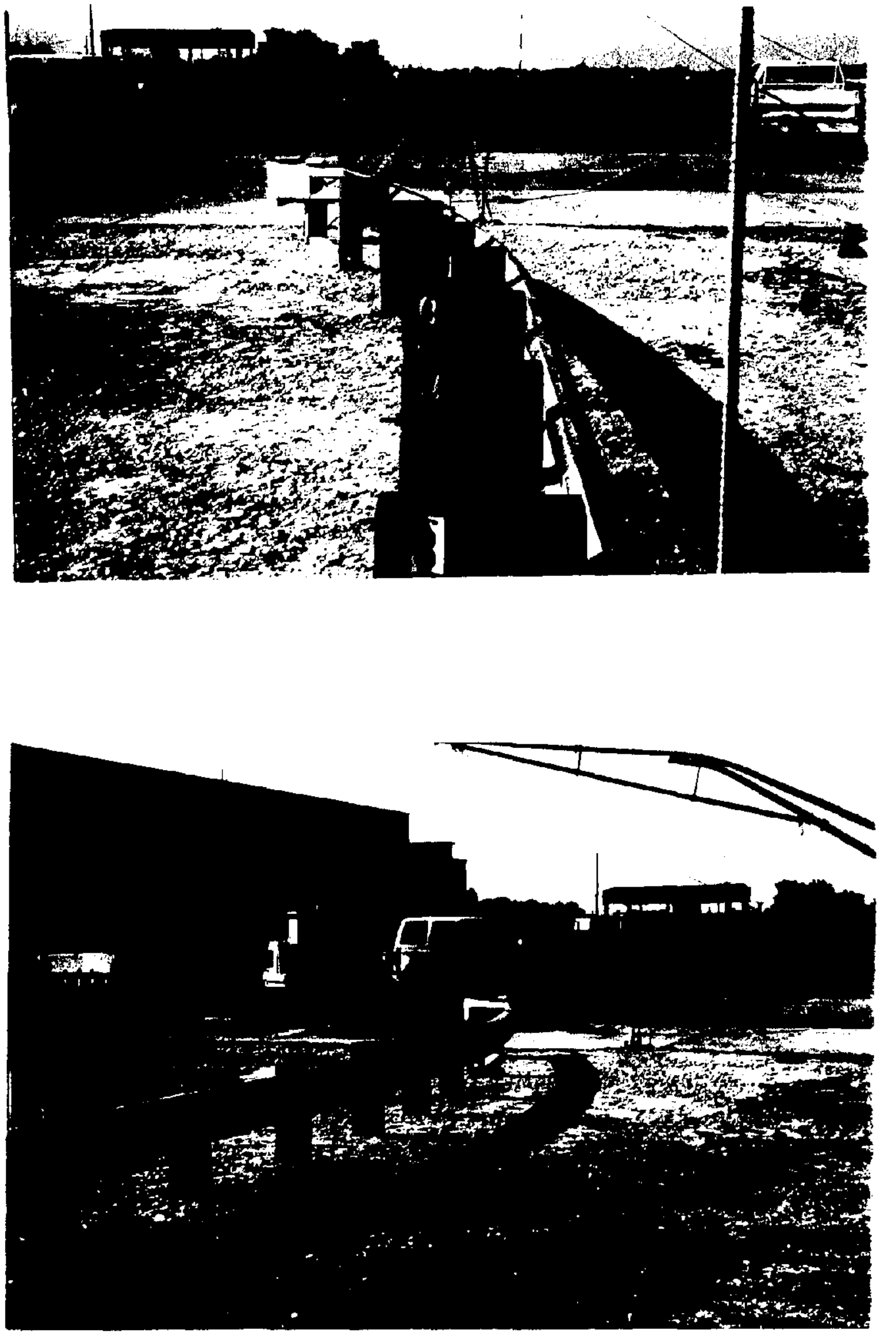


Figure 98. Modified MELT (terminal section) before tests 471470-35 and 36.

terminal, followed by six 1270-mm (4-ft, 2-in) spans. This then transitioned into the standard G4(2W) guardrail system. The height to the center of the W-beam rail element in the terminal section was the same as that for the length-of-need section at 550 mm (21.7 in). The end of the terminal was flared 1500 mm (59.1 in) from the tangent section of the guardrail, which began 7.62 m (25 ft) from the end of the terminal. A simple radius of 19 m (62.3 ft) was used over the first 7.62 m (25 ft) of the terminal. The corresponding offsets for posts 1 through 6 were 1500, 850, 380, 170, 40, and 0 mm (59.1, 33.5, 15.0, 6.7, 1.6, and 0 in), respectively. Note that the first two 3810-mm (12-ft, 6-in) sections of the W-beam rail element for the end terminal were shop curved to a nominal radius of 19 m (62.3 ft).

The buffered nose piece had two bolted-on diaphragms. Posts 1 and 2 were breakaway wooden posts installed in 1525-mm- (5-ft-) long, TS 152-mm × 203-mm × 4.8-mm (TS 6-in × 8-in × 0.1875-in) steel foundation tubes with 460-mm × 610-mm × 6-mm (18-in × 24-in × 1/4-in) soil plates. A 160-mm × 50-mm (6-in × 2-in) channel strut connected the two foundation tubes at ground level for increased anchorage capacity. The posts were 1110 mm (43 in) long with cross-sectional dimensions of 140 mm × 190 mm (5-1/2 in × 7-1/2 in). A 64-mm- (2.5-in-) diameter hole was drilled through these posts at ground level to facilitate breaking of the posts upon impact. The post bolt hole of the end post (i.e., post 1) was slotted with the dimensions of 20 mm × 70 mm (3/4 in × 2-3/4 in). The second post (post 2) was not bolted to the W-beam rail element, but rested on a shelf angle attached to the post. Photographs showing the details for posts 1 and 2 are shown in figure 99.

Posts 3 through 8 in the terminal section were 1830-mm- (6-ft-) long wooden breakaway line posts or CRT posts, and the W-beam rail element was not bolted onto these posts. In other words, the W-beam rail element was bolted at the end post (post 1) and then the next bolted post was post 9, for an unsupported rail length of 11.4 m (37 ft, 6 in). However, the rail element was supported by shelf angles at posts 2, 4, and 7. Standard wooden line posts were then used starting at post 9 with the standard 1905 mm (6 ft, 3 in) spacing. Photographs showing the details at posts 1 through 9 are shown in figure 100.

14.2 TEST NO. 471470-35 (NCHRP REPORT 350 TEST DESIGNATION 3-31)

Test vehicle: 1991 Chevrolet 2500 Pickup	Impact speed: 102.4 km/h (63.6 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 0 degrees
Gross static weight: 2076 kg (4577 lb)	

The vehicle impacted the nose of the terminal 19 mm (0.75 in) left of post 1.Upon impact, the W-beam rail element began to flex, twist, and move away from posts 2 and 3. The vehicle contacted the first post, which fractured at ground level. The W-beam rail element began to flex and move away from post 2 and then from posts 3 through 7. A bend in the rail element began to form just past post 2 and the W-beam rail element began pulling away from post 8. The vehicle made contact with post 2, which fractured at ground level.

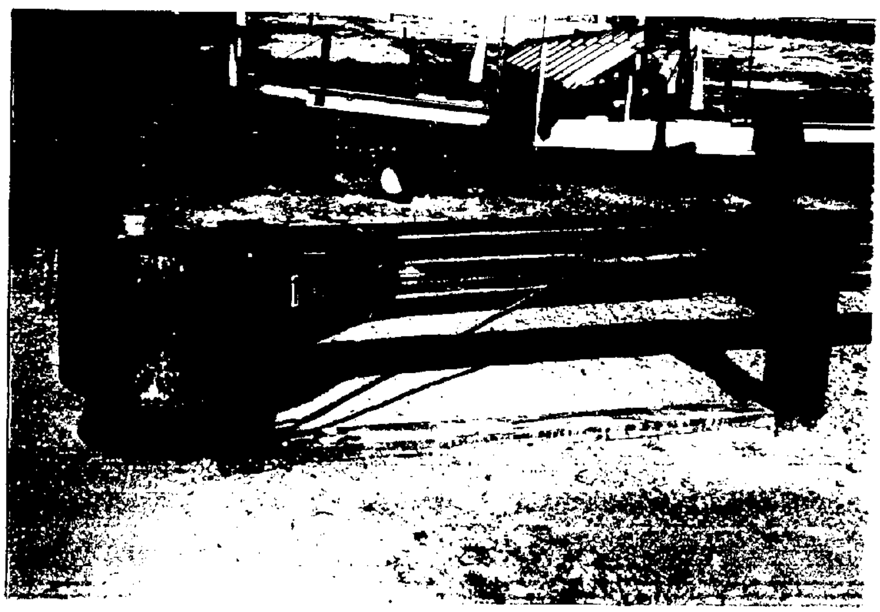


Figure 99. Details for posts 1 and 2.

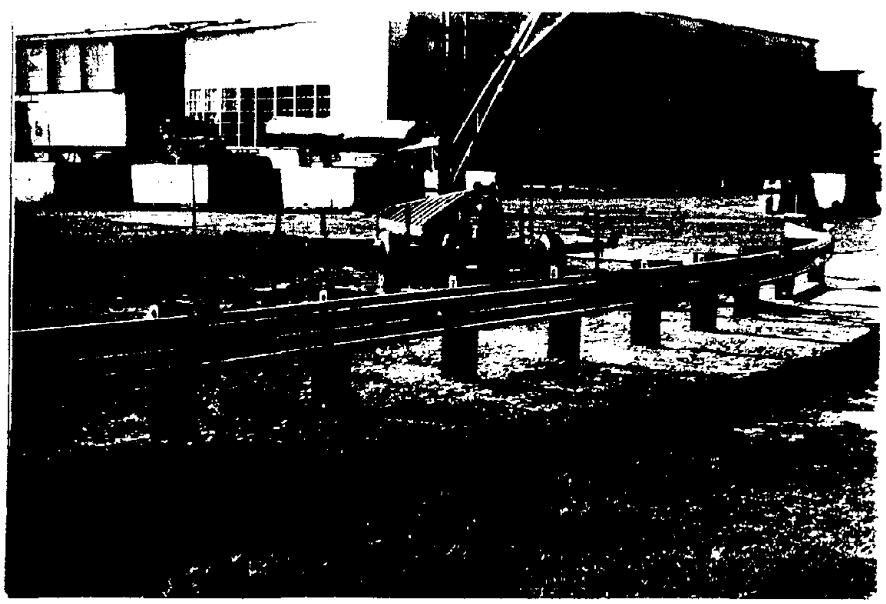


Figure 100. Photographs showing details at posts 1 through 9.

The nose then contacted post 3. The W-beam rail element began to buckle at post 4, and the nose contacted the post. Maximum dynamic deflection of the rail of 2.03 m (6.7 ft) toward the traffic side occurred at the buckle formed at post 4. The vehicle lost contact with the installation traveling at a speed of 87.7 km/h (54.5 mi/h) and at an exit angle of 4.1 degrees behind the installation. After exiting from the test installation, the vehicle continued forward and subsequently impacted a concrete barrier protecting a camera stand at the downstream end of the test installation. The vehicle came to rest upright approximately 85 m (280 ft) downstream of the initial point of impact and 6 m (19 ft) behind the installation. Note that the brakes were not applied until after the secondary impact with the concrete barrier. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 101.

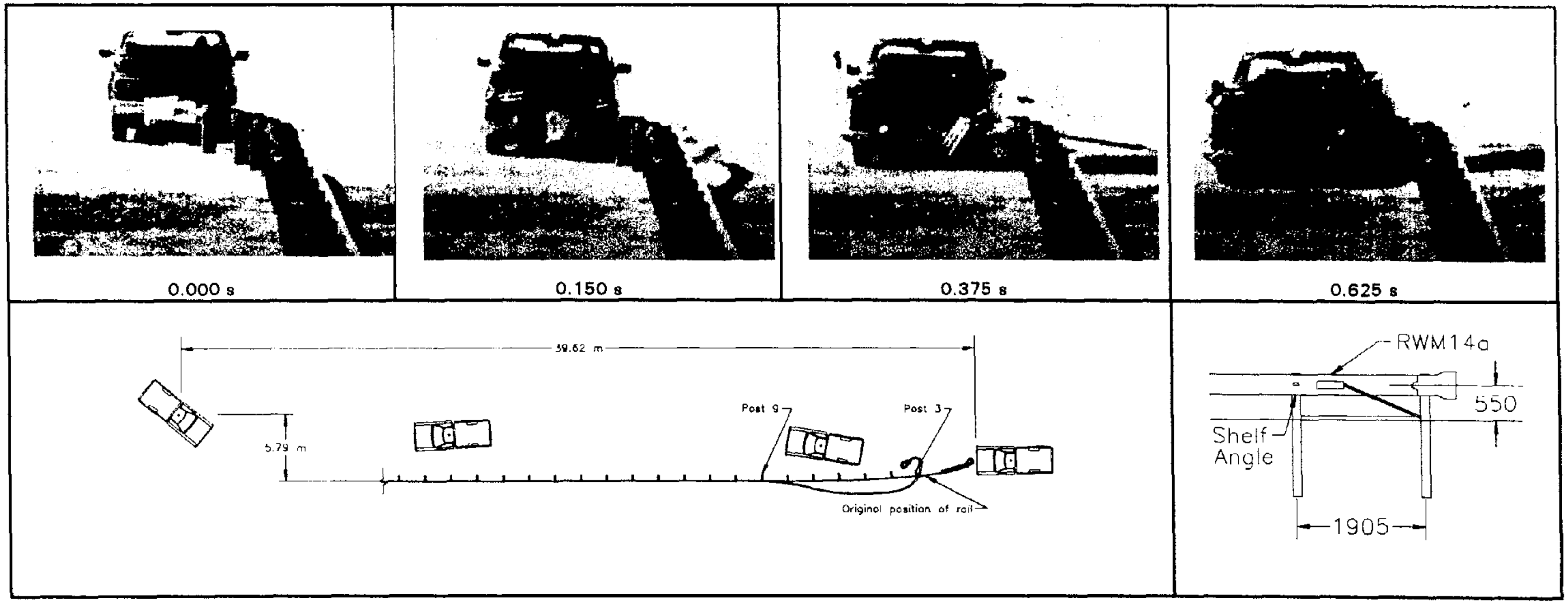
The W-beam rail element was deformed between posts 1 through 9. The foundation tubes were displaced 35 mm (1.4 in) at post 1 and 50 mm (2.0 in) at post 2. Posts 1 and 2 fractured at ground level and came to rest just behind the installation. There were marks on the rear of posts 3 and 4 where the nose of the terminal was pushed into them as the vehicle passed behind the installation. Maximum permanent deformation of the rail was 1.66 m (5.4 ft) toward the traffic side at post 4.

Most of the damage sustained by the vehicle occurred in the secondary impact with the concrete barrier. Maximum exterior crush at the left front of the vehicle was 840 mm (33.0 in) at bumper height. Maximum crush in the left side floor pan area was 234 mm (9.2 in).

14.3 TEST NUMBER 471470-36 (NCHRP REPORT 350 TEST DESIGNATION 3-35)

Test vehicle: 1989 GMC 2500 Pickup	Impact speed: 101.0 km/h (62.8 mi/h)
Test inertia weight: 2000 kg (4409 lb)	Impact angle: 21.5 degrees
Gross static weight: 2076 kg (4577 lb)	

The vehicle impacted the terminal 152 mm (6.0 in) upstream of post 3. Upon impact, post 3 began to move laterally and the W-beam rail element began to flex and move away from post 6. The right front tire made contact with post 4 and the W-beam rail element was moving away from post 7. As the vehicle continued forward, the W-beam rail element began moving back toward posts 6 and 7. The vehicle contacted post 5, fracturing the post. Post 6 fractured and the front of the vehicle made contact with post 6. The right front tire contacted post 6, and then post 7, causing the post to fracture just below ground level. The lower edge of the W-beam rail element began to tear at post 7, and the front of the vehicle made contact with post 8 at an angle of 2.2 degrees. The W-beam rail element then ruptured completely. The vehicle made contact with post 9 and was traveling parallel with the length-of-need section at a speed of 53.6 km/h (33.3 mi/h). The vehicle made contact with post 10, rotated counterclockwise, and came to rest with the right front wheel near post 10. A summary of pertinent data from the electronic instrumentation, high-speed film, and field measurements is given in figure 102.

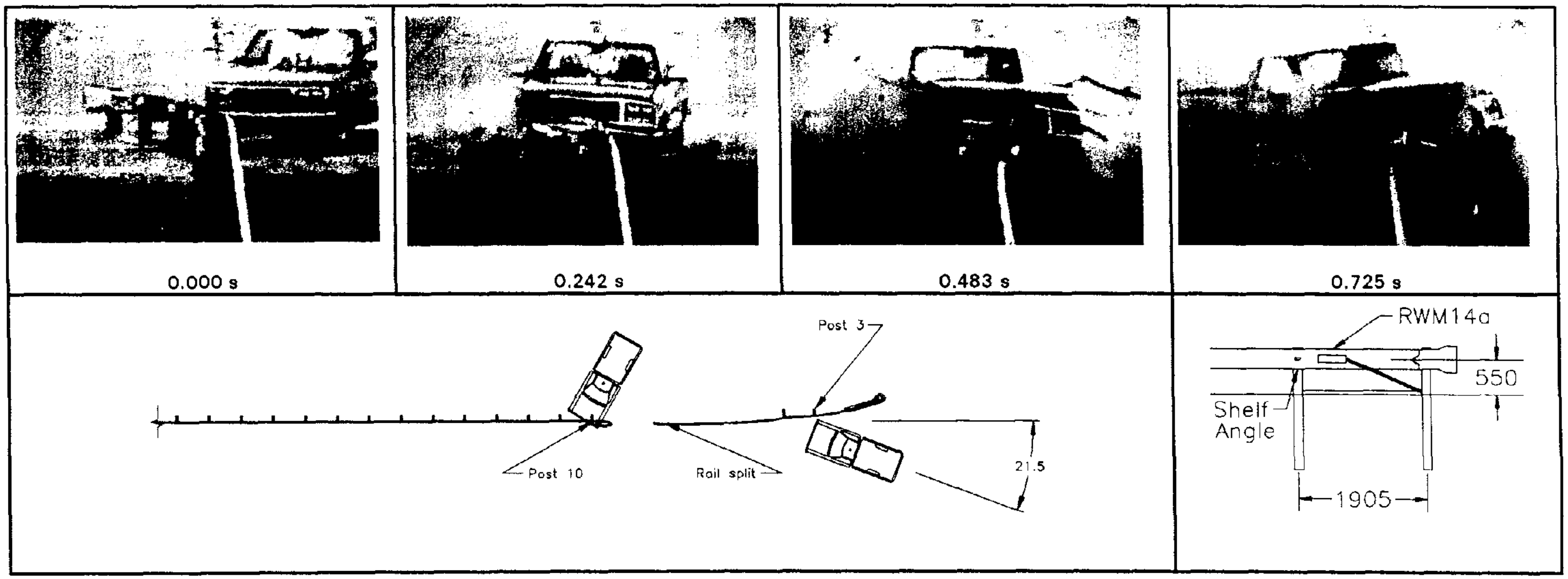


General Information	
Test Agency	Texas Transportation Institute
Test No.	471470-35
Date	07/26/95
Test Article	
Type	Terminal
Name or Manufacturer	Modified MELT
Installation Length (m)	53 m (175 ft)
Size and/or Dimension and Material of Key Elements	Mod. Metric MELT on G4(2W) Guardrail
Soil Type and Condition	Strong Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1991 Chevrolet 2500
Mass (kg) Curb	1907 (4200 lb)
Test Inertial	2000 (4405 lb)
Dummy	75 (165 lb)
Gross Static	2076 (4573 lb)

Impact Conditions	
Speed (km/h)	102.4 (63.6 mi/h)
Angle (deg)	0 deg - End-on
Exit Conditions	
Speed (km/h)	87.7 (54.5 mi/h)
Angle (deg)	4.1 Behind the Rail
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.1 (10.0 ft/s)
y-direction	0.3 (1.0 ft/s)
THIV (optional)	
Ridedown Accelerations (g's)	
x-direction	3.5
y-direction	-11.1
PHD (optional)	
ASI (optional)	
Max. 0.050-s Average (g's)	
x-direction	-6.0
y-direction	2.5
z-direction	2.3

Test Article Deflections (m)	
Dynamic	2.03 (6.7 ft)
Permanent	1.66 (5.4 ft)
Vehicle Damage	
Exterior	
VDS	12FC4
CDC	12FYEW3
Interior	
OCDI	AS0000000
Maximum Exterior Vehicle Crush (mm)	840 (33.1 in)
Max. Occ. Compart. Deformation (mm)	234 (9.2 in)
Post-Impact Behavior	
Max. Roll Angle (deg)	3
Max. Pitch Angle (deg)	-8
Max. Yaw Angle (deg)	9

Figure 101. Summary of results for test 471470-35.



General Information		**Impact Conditions**		**Test Article Deflections (m)**	
Test Agency	Texas Transportation Institute	Speed (km/h)	101.0 (62.8 mi/h)	Dynamic	1.3 (4.1 ft)
Test No.	471470-36	Angle (deg)	21.5	Permanent	Rail Ruptured
Date	08/07/95	**Exit Conditions**			
Test Article		Speed (km/h)	N/A	**Vehicle Damage**	
Type	Terminal	Angle (deg)	N/A	Exterior	
Name or Manufacturer	Mod. Metric MELT	**Occupant Risk Values**		VDS	01FR5
Installation Length (m)	53 m (175 ft)	Impact Velocity (m/s)		CDC	01FZEW3
Size and/or Dimension		x-direction	6.8 (22.4 ft/s)	Interior	
and Material of Key	Metric MELT on	y-direction	1.1 (3.5 ft/s)	OCDI	AS0000000
Elements	G4(2W) Guardrail	THIV (optional)		Maximum Exterior	
Soil Type and Condition	Strong Soil, Dry	Ridedown Accelerations (g's)		Vehicle Crush (mm)	330 (13.0 in)
Test Vehicle		x-direction	-14.5	Max. Occ. Compart.	
Type	Production	y-direction	15.0	Deformation (mm)	11 (0.4 in)
Designation	2000P	PHD (optional)			
Model	1989 GMC 2500	ASI (optional)		**Post-Impact Behavior**	
Mass (kg) Curb	1991 (4385 lb)	Max. 0.050-s Average (g's)		Max. Roll Angle (deg)	8
Test Inertial	2000 (4405 lb)	x-direction	-7.0	Max. Pitch Angle (deg)	7
Dummy	75 (165 lb)	y-direction	-5.4	Max. Yaw Angle (deg)	-70
Gross Static	2075 (4570 lb)	z-direction	-3.7		

Figure 102. Summary of results for test 471470-36.

The W-beam rail element was deformed between posts 3 through 12, partially torn at the splice at post 6, ruptured at the post 7 location, partially torn at 3.0 m (10 ft) downstream from post 6, and buckled at the splice at post 9. Maximum dynamic deflection before the W-beam rail element ruptured was 1.3 m (4.1 ft). Posts 5, 6, and 7 fractured at or just below ground level, and posts 8 and 9 were split vertically. Lateral post deflections occurred at posts 1 through 11. Debris from the terminal extended from the point of impact downstream 33 m (107 ft) and 7 m (24 ft) behind the installation.

The vehicle's right-side upper and lower A-arms, tie rods, and stabilizer bar were damaged and the right front frame was bent. Also damaged were the bumper, hood, grill, fan, radiator, left and right front quarter panels, and the right-side door. Maximum exterior crush was 330 mm (13.0 in) to the center front at bumper height. Maximum deformation into the occupant compartment was 11 mm (0.4 in) in the lower floor pan area.

14.4 SUMMARY OF FINDINGS

In the end-on test (test no. 471470-35), the modified MELT gated as designed, allowing the vehicle to penetrate behind the guardrail installation in a controlled manner. There were no detached elements or debris from the test article that penetrated or showed the potential for penetrating the occupant compartment, or presented undue hazard to adjacent traffic. Posts 1 through 4 fractured at ground level, but remained near the installation. There was minimal deformation or intrusion into the occupant compartment. The vehicle remained upright and stable during the collision and upon loss of contact for the initial impact. All occupant risk values are well within the recommended limits set forth in NCHRP Report 350.

In the redirection test (test no. 471470-36), the W-beam rail element ruptured at the post 7 location, approximately 8.8 m (29 ft) downstream from the nose of the terminal, allowing the vehicle to penetrate behind the guardrail. There were no detached elements or debris from the test article that penetrated or showed the potential for penetrating the occupant compartment, or presented undue hazard to adjacent traffic. Posts 5 through 7 fractured at or just below ground level, and posts 8 and 9 were split vertically. There was minimal deformation or intrusion into the occupant compartment. The vehicle remained upright and stable during the collision sequence. All occupant risk values are well within the recommended limits set forth in NCHRP Report 350. However, the test was judged to be unsatisfactory because of the rupture of the rail element, which allowed the vehicle to penetrate behind the guardrail test installation.

In summary, the modified MELT was judged to have performed satisfactorily in the end-on test, but failed in the redirection test in accordance with evaluation criteria set forth in NCHRP Report 350, as shown in tables 43 and 44, respectively.

Table 43. Assessment of results of test on modified metric MELT, end-on.

Test Agency: Texas Transportation Institute | Test No.: 471470-35 | Test Date: 07/26/95

Evaluation Criteria	Test Results	Assessment
Structural Adequacy C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The Modified MELT gated as designed, allowing the vehicle to penetrate behind the guardrail installation in a controlled manner.	Pass
Occupant Risk D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Posts 1 and 2 fractured at ground level, but remained near their original location. It appeared from review of the high-speed film that there was minimal, if any, deformation into the occupant compartment during the initial impact. Most of the damage to the vehicle was caused by the second impact with a concrete barrier protecting a camera stand.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable during the collision and upon loss of contact.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component: Longitudinal and lateral — Preferred: 9 — Maximum: 12	Longitudinal Occupant Impact Velocity = 3.1 m/s Lateral Occupant Impact Velocity = 2.7 m/s	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component: Longitudinal and lateral — Preferred: 15 — Maximum: 20	Longitudinal Occupant Ridedown = 3.5 g Lateral Occupant Ridedown = 11.1 g	Pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was no intrusion into adjacent traffic lanes.	Pass
N. Vehicle trajectory behind the test article is acceptable.	The vehicle penetrated behind the guardrail installation in a controlled manner.	Pass

Table 44. Assessment of results of test on modified MELT, redirection test.

Test Agency: Texas Transportation Institute — Test No.: 471470-36 — Test Date: 08/07/95

Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	The W-beam rail element ruptured, allowing the vehicle to penetrate behind the test article. Maximum lateral deflection of the W-beam was 1.3 m (4.1 ft) before the W-beam rail element ruptured.	Fail
<u>Occupant Risk</u>		
D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	Posts 5, 6, and 7 broke off at ground level, and were thrown behind the installation (maximum distance of 32.6 m (107 ft) down 7.3 m (24 ft) behind). Maximum deformation of 11 mm (0.4 in) occurred in the floorpan area.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright during and after the collision	Pass
<u>Vehicle Trajectory</u>		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	There was minimal intrusion into adjacent traffic lanes.	Pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	Longitudinal Occupant Impact Velocity = 6.8 m/s (22.4 ft/s) Longitudinal Ridedown Acceleration = -14.5 g's	Pass
M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	Vehicle penetrated the W-beam rail element and came to rest behind the installation.	N/A

XV. LABORATORY AND PENDULUM TESTING OF MODIFIED BREAKAWAY WOODEN POSTS

The MELT is one of the end terminals currently approved for use with W-beam guardrail systems. The MELT has successfully met all evaluation criteria set forth in NCHRP Report 230. However, with the adoption of NCHRP Report 350 by FHWA as the official guidelines for crash testing of roadside safety features, it became necessary to retest the MELT to the new guidelines. Specifically, one of the design test vehicles specified in NCHRP Report 230, the 2044-kg (4500-lb) passenger car, was replaced by a 2000-kg (4405-lb) pickup truck (2000P) under NCHRP Report 350 guidelines. An effort was therefore undertaken by FHWA to evaluate the MELT with the 2000P test vehicle according to NCHRP Report 350 guidelines.

The MELT was tested with the 2000P test vehicle in two previous tests under this study, one a redirection test at the beginning of length of need (test no. 471470-32) and the other an end-on test (test nos. 471470-34). The MELT failed to perform satisfactorily in both tests. As a result of these two failed crash tests, FHWA redesigned the MELT and the redesigned terminal (hereinafter referred to as the modified MELT) was then crash tested to evaluate its safety performance in accordance with NCHRP Report 350 guidelines. The modified MELT also failed to perform satisfactorily in the small car end-on test, in which an 820-kg (1808-lb) passenger car impacted the terminal end-on with the front quarter point of the vehicle aligned with the center of the end post at a nominal speed of 100 km/h (62.2 mi/h). The unsatisfactory performance was attributed to the end post, which failed to break away properly.

An effort was then undertaken by FHWA to modify the breakaway wooden MELT end post so that the post would break away more readily. Figure 103 shows a schematic of the modified breakaway wooden MELT post. Longitudinal slots are cut along the centerline of the weak axis of the post both above and below the post bolt slot. Laboratory tests were first conducted to determine the appropriate dimensions for these slots. Upon selection of the optimal dimensions for the longitudinal slots, a series of pendulum tests were then conducted to assess the anchorage capacity and the breakaway characteristics of the modified MELT end post and a line post modified in a similar manner.

15.1 LABORATORY TESTING

A series of 12 pseudo-static laboratory tests were conducted on the modified wooden end post design intended for use in the modified MELT. Details of the modified MELT end post as tested in the laboratory program are shown in figure 104. An 8-mm- (0.31-in-) wide longitudinal slot is cut down the center and along the long face of the post from the top of the post to a depth of 25 mm (1.0 in) above the rectangular post bolt slot. A second 8-mm- (0.31-in-) wide longitudinal slot is then plunge cut from a specified distance below the post bolt slot to the bottom of the 64-mm- (2-1/2 in-) diameter hole near the ground line.

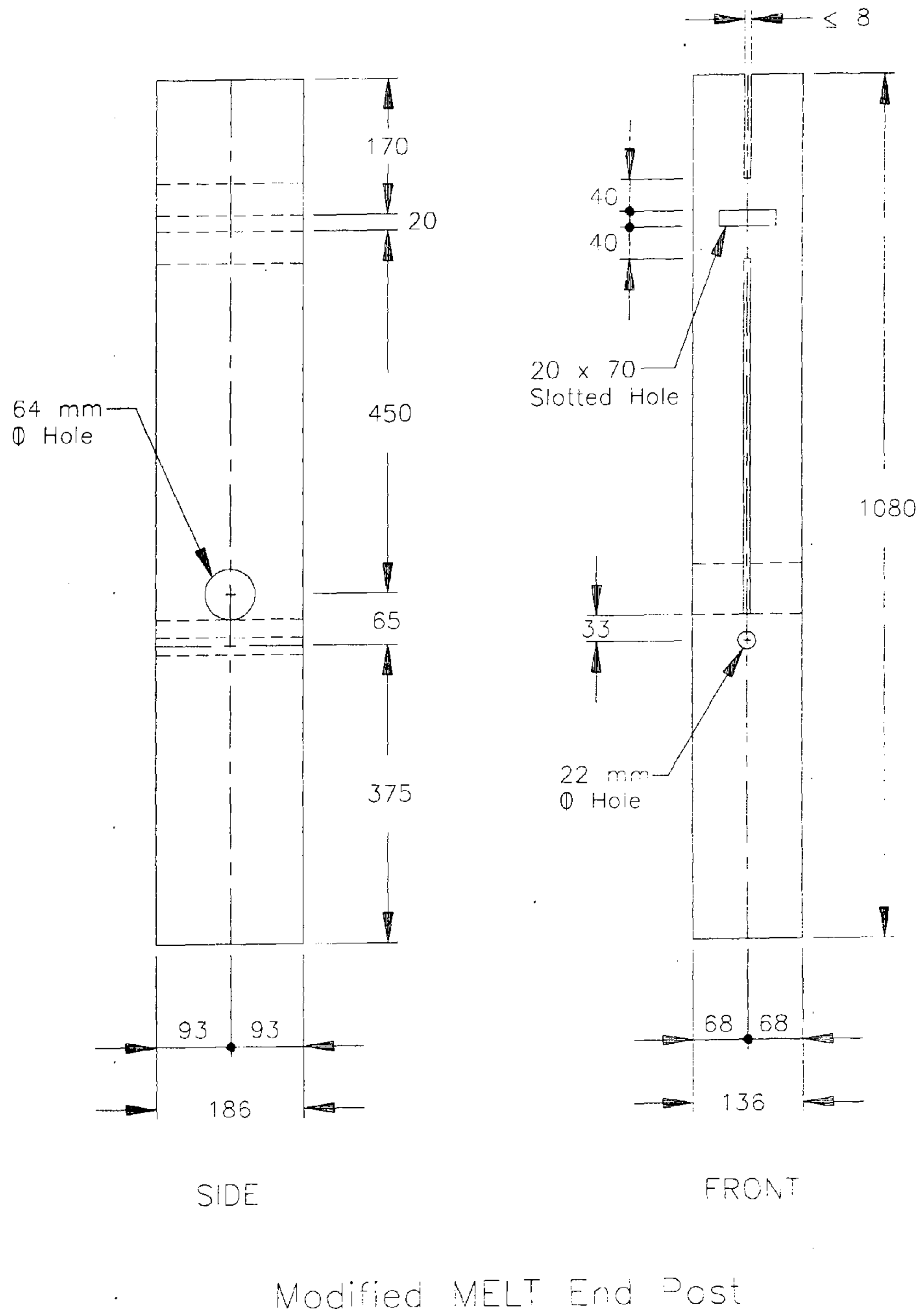


Figure 103. Schematic of modified breakaway wooden MELT post.

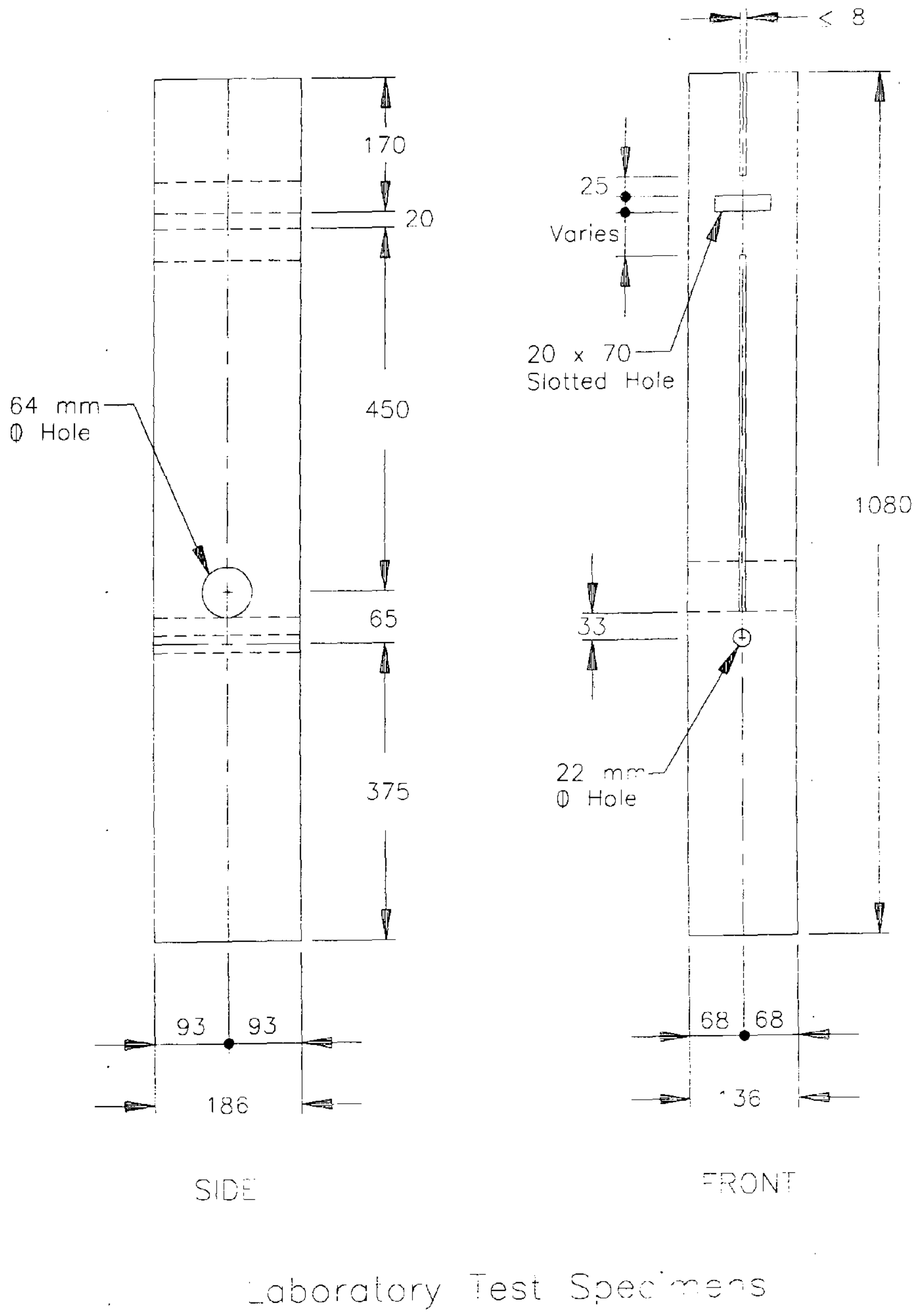


Figure 104. Details of the modified MELT post used in laboratory testing.

The objective of the laboratory test program was to determine the optimal distance from the post bolt slot to the beginning of the second longitudinal slot based on the fracture strength of the post. Three different distances from the post bolt slot to the beginning of the second longitudinal slot were evaluated: 50, 75, and 100 mm (2.0, 3.0, and 4.0 in). Four specimens were tested for each of the three configurations, for a total of 12 tests.

15.1.1 Laboratory Testing Procedures

A cantilever-type flexure test was used to determine the ultimate load capacity and force/deflection characteristics of the modified MELT posts. A fixed boundary condition was imposed by securing the base of each post inside a fabricated steel fixture that was bolted to a load carrying floor. The posts, which were held in a horizontal position with the long face of the post oriented parallel to the floor, were inserted into the test fixture approximately 400 mm (15.7 in). This configuration placed the bottom edge of the 64-mm- (2-1/2 in-) diameter hole about 8 mm (0.31 in) beyond the end of the fixture, which is comparable to the installation of a wooden end posts in a steel foundation tube. A schematic of the test setup is shown in figure 105.

A vertical load was applied to each post a distance of 250 mm (10.0 in) from the end of the fixture at a rate of 102 mm/s (4 in/s). The load was applied to the post through a specially fabricated yoke. The bottom channel bracket of the yoke assembly was designed to pivot and remain in contact with the post as it deflected under the applied vertical load. The load was measured using a pull rod load cell that was calibrated to 178 kN (40 kips). In order to provide better resolution, the load was gained to a scale of 53.3 kN (12 kips). The displacement of the post was measured at the point of the applied load using a 381-mm (15-in) Tempasonic transducer that was gained to a scale of 254 mm (10 in) for better data resolution. The load and displacement data were digitally recorded using a computerized data acquisition system and were visually displayed during testing using separate volt meters. Visual inspection of the posts was conducted before and after each test. The dimensions of each post and the location and size of any observed imperfections (e.g., knots, splits, etc.) were recorded. Also, the laboratory tests were documented with a VHS-format camcorder.

Plots of time versus force, time versus displacement, and force versus displacement were generated from the electronic data for each of these laboratory tests.

15.1.2 Laboratory Test Results

Table 45 presents a summary of the laboratory test results. As may be expected, the average force required to fracture the post increases as the length between the bottom of the post bolt slot and the top of the second longitudinal slot increases, from 23.36 kN (5.25 kips)

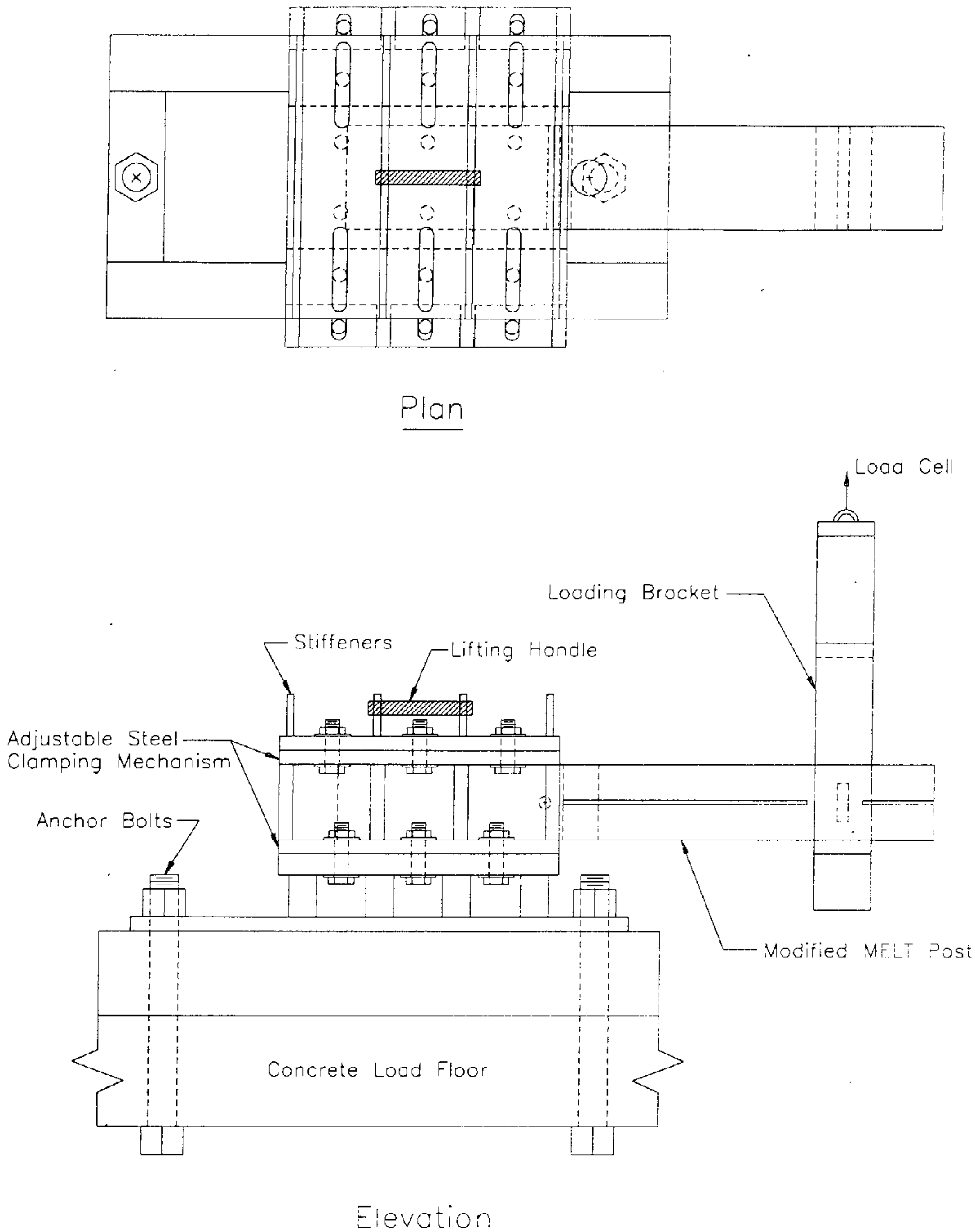


Figure 105. Schematic of test setup.

Table 45. Results of laboratory tests on modified MELT end posts.

Specimen[a]	Maximum Load (kips)	Maximum Load (kN)
50-A	5.67	25.23
50-B	4.81	21.40
50-C	4.46	19.85
50-D	6.07	27.01
Average	5.25	23.36
75-A	5.09	22.65
75-B	10.37	46.15
75-C	9.12	40.58
75-D[b]	6.27	27.90
Average	7.71	34.32
100-A[b,c]	4.93	21.94
100-B	8.44	37.56
100-C[b]	10.67	47.48
100-D[b]	8.91	39.65
Average[d]	9.34	41.56

[a] 50, 75, 100 series denotes distance (mm) from post bolt slot to saw cut.
[b] Plug between saw cuts did not fail.
[c] Strength affected by presence of large knot.
[d] Average values exclude results of specimen 100-A (see note "c" above).

for a length of 50 mm (2.0 in) to 34.32 kN (7.71 kips) for a length of 75 mm (3.0 in), to 36.66 kN (8.24 kips) for a length of 100 mm (4.0 in). Note that one of the 100-mm (4.0-in) specimens (no. 100-A) had a knot in the immediate vicinity of the 64-mm- (2-1/2 in-) diameter hole, which significantly reduced the fracture load to only 21.94 kN (4.93 kips). The fracture load for this specimen was considered atypical and thus was not included in the calculation of the average fracture load.

Three of the four specimens (nos. 100-A, 100-C, and 100-D) with lengths of 100 mm (4.0 in) between the bottom of the post bolt slot and the top of the second longitudinal slot fractured without shearing the plug (i.e., the solid portion of the post between the two longitudinal slots). This indicates that the fracture loads for these posts are probably not controlled by the longitudinal slots and the fracture load of these posts would approach that of an unmodified MELT end post. Similarly, one of the four specimens (no. 75-D) with lengths of 75 mm (3.0 in) between the bottom of the post bolt slot and the top of the second longitudinal slot also fractured without shearing the plug.

Based on the results of these laboratory tests, FHWA decided that the optimal dimensions are 40 mm (1.6 in) for both the length between the bottom of the top longitudinal slot to the top of the post bolt slot and between the bottom of the post bolt slot to the top of the second longitudinal slot. This provides a total length of 80 mm (3.2 in) for the plug, which is slightly higher than the combined length of 75 mm (3.0 in) for the configuration of 25 mm (1.0 in) between the bottom of the top longitudinal slot to the top of the post bolt slot and 50 mm (2.0 in) between the bottom of the post bolt slot to the top of the second longitudinal slot.

15.2 PENDULUM TESTING

Upon selection of the optimal dimensions for the slots, a series of 31 pendulum tests, as listed in table 46, were conducted to evaluate the anchorage capacity and breakaway characteristics of the modified MELT end posts and those of a modified line post with a similar design.

The first pendulum test (test no. P01) was conducted to assess if the modified end posts have sufficient anchorage capacity for use with the modified MELT. There was concern that, with the incorporation of the longitudinal slots in the weak axis, the posts might have been weakened to the extent that they no longer have the required anchorage capacity. Figure 106 shows the test setup for this pendulum test, and photographs of the test installation are shown in figure 107.

The test installation simulated the anchorage setup for the MELT and consisted of: two 152 mm × 203 mm × 4.8 mm (6 in × 8 in × 3/16 in), 2000-mm- (78.75-in-) long foundation tubes installed in strong soil with no soil plates, spaced at 1.91 m (6 ft, 3 in); a 152 mm × 51 mm (6 in × 2 in) channel ground strut connecting the two foundation tubes; two modified MELT end posts (as shown previously in figure 104) installed in the two

Table 46. Pendulum test matrix.

Test No.	Test Article	Description
1	Anchorage Assembly	Two foundation tubes with ground strut installed in soil; two modified MELT end posts; 3.8-m (12-ft, 6-in) section of W-beam rail connected to back of pendulum with cable; and breakaway cable anchorage assembly. Installed behind pendulum so that pendulum applies a tensile force axially on the W-beam rail; center of pendulum at 550 mm above ground.
2-4	Modified MELT End Post	Two foundation tubes with ground strut installed in soil; modified MELT end post in first foundation tube; pendulum impacts post on weak axis at 550 mm above ground.
5-7	Standard MELT End Post	Two foundation tubes with ground strut installed in soil; standard MELT end post in first foundation tube; pendulum impacts post on weak axis at 550 mm above ground.
8-10	Modified MELT End Post	Two foundation tubes with ground strut installed in soil; modified MELT end post in first foundation tube; pendulum impacts post on strong axis at 550 mm above ground.
11-13	Standard MELT End Post	Two foundation tubes with ground strut installed in soil; standard MELT end post in first foundation tube; pendulum impacts post on strong axis at 550 mm above ground.
14-16	Modified MELT End Post	Two foundation tubes with ground strut installed in soil; modified MELT end post in first foundation tube; pendulum impacts post across diagonal of post at 550 mm above ground.
17-19	Standard MELT End Post	Two foundation tubes with ground strut installed in soil; standard MELT end post in first foundation tube; pendulum impacts post across diagonal of post at 550 mm above ground.
20-21	Slotted Line Post	Slotted line post installed in soil; pendulum impacts post on weak axis at 300 mm above ground.
22-23	Standard CRT Post	Standard CRT post installed in soil; pendulum impacts post on weak axis at 300 mm above ground.
24-25	Slotted Line Post	Slotted line post installed in soil; pendulum impacts post on strong axis at 550 mm above ground.
26-27	Standard CRT Post	Standard CRT post installed in soil; pendulum impacts post on strong axis at 550 mm above ground.
28-29	Slotted Line Post	Slotted line post installed in soil; pendulum impacts post across diagonal of post at 550 mm above ground.
30-31	Standard CRT Post	Standard CRT post installed in soil; pendulum impacts post across diagonal of post at 550 mm above ground.

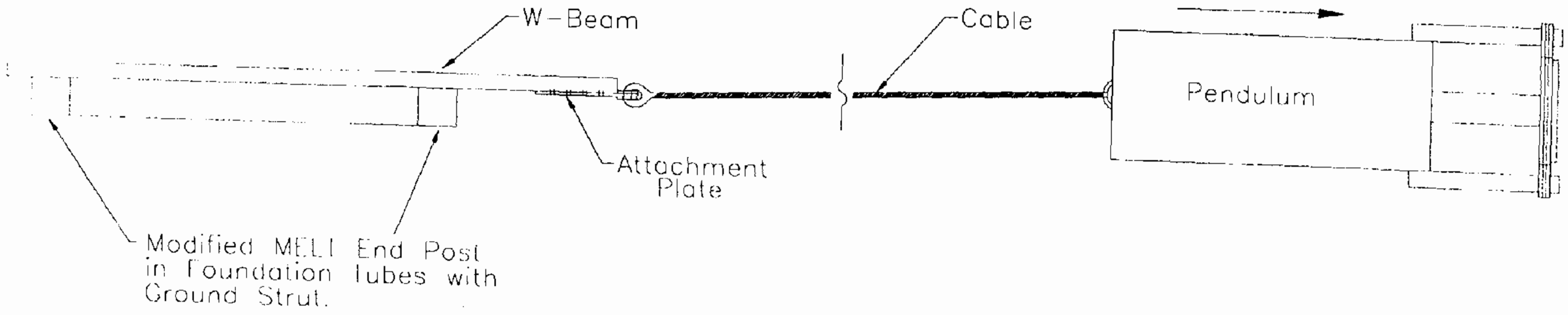


Figure 106. Setup for first pendulum test (P01).

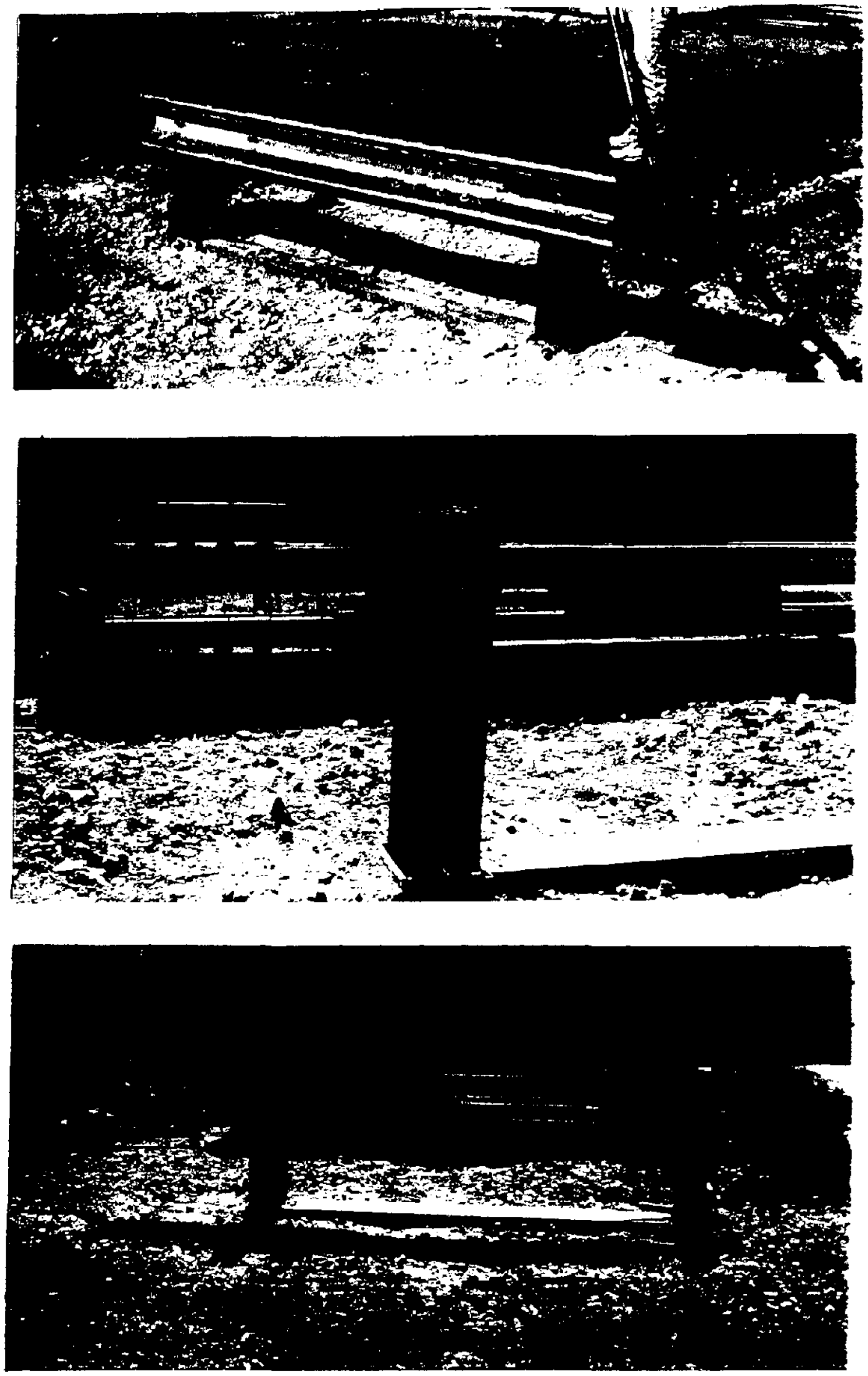


Figure 107. Photographs of P01 test installation.

foundation tubes; a 3.8-m (12-ft, 6-in) section of W-beam rail bolted to both posts, and a standard breakaway cable anchorage assembly. The downstream end of the W-beam rail was connected to a cable that was attached to the back of the pendulum mass. The length of the cable was such that the cable would become taut at the apex (bottom) of the pendulum swing. The test installation was behind and in line with the centerline of the pendulum mass so that the pendulum mass would apply a tensile force axially on the W-beam rail. The center of the pendulum mass was set at 550 mm (21-5/8 in) above ground level.

The breakaway characteristics of the modified MELT end post and those of the standard MELT end post were evaluated in a series of 18 pendulum tests (test nos. P02 through P19). The test installation consisted of: two 152-mm × 203-mm × 4.8-mm (6-in × 8-in × 3/16-in), 2000-mm- (78.75-in-) long foundation tubes installed in strong soil with no soil plates, spaced at 1.91 m (6 ft, 3 in); a 152-mm × 51-mm (6-in × 2-in) channel ground strut connecting the two foundation tubes; and a modified or standard MELT end post installed in the first foundation tube. Each of the two post designs (i.e., modified and standard) was tested in three different configurations: along the weak axis, along the strong axis, and across the diagonal of the post. The orientation of the two foundation tubes was varied to accommodate the specific test configuration. Three specimens were tested for each of the two end post designs and the three different configurations, for a total of 18 tests. The center of the pendulum mass was set at 550 mm (21-5/8 in) above ground level. Photographs of the test installation are shown in figure 108.

The remaining 12 pendulum tests (test nos. P20 through P31) were conducted to evaluate the breakaway characteristics of a modified line post and those of the standard CRT post. Two specimens were tested for each of the two post designs (i.e., modified line post and standard CRT post) and three different configurations (i.e., along the weak axis, along the strong axis, and across the diagonal), for a total of 12 tests. The modified line post, a schematic of which is shown in figure 109, has a design similar to that of the modified MELT end post except for the length of 1830 mm (72.0 in). The modified line post is intended as a replacement for the standard CRT post in the modified MELT.

The test installation consisted of installing a modified line post or a standard CRT post in strong soil. The orientation of the post varied according to whether the impact with the post was along the weak axis, the strong axis, or across the diagonal of the post. The center of the pendulum mass was set at 300 mm (11.8 in) above ground level for impacts along the weak axis and 550 mm (21-5/8 in) above ground level for impacts along the strong axis and across the diagonal of the post. Photographs of the test installation are shown in figure 110.

15.2.1 Pendulum Testing Procedures

The pendulum tests were conducted at the Texas Transportation Institute outdoor pendulum testing facility, as shown in figure 111. The pendulum mass, weighing approximately 1066 kg (2350 lb), was suspended from four cables so that the pendulum mass would remain level during the swing. The test installation was set up so that the initial point

Figure 10? Test installation for P02 through P1?

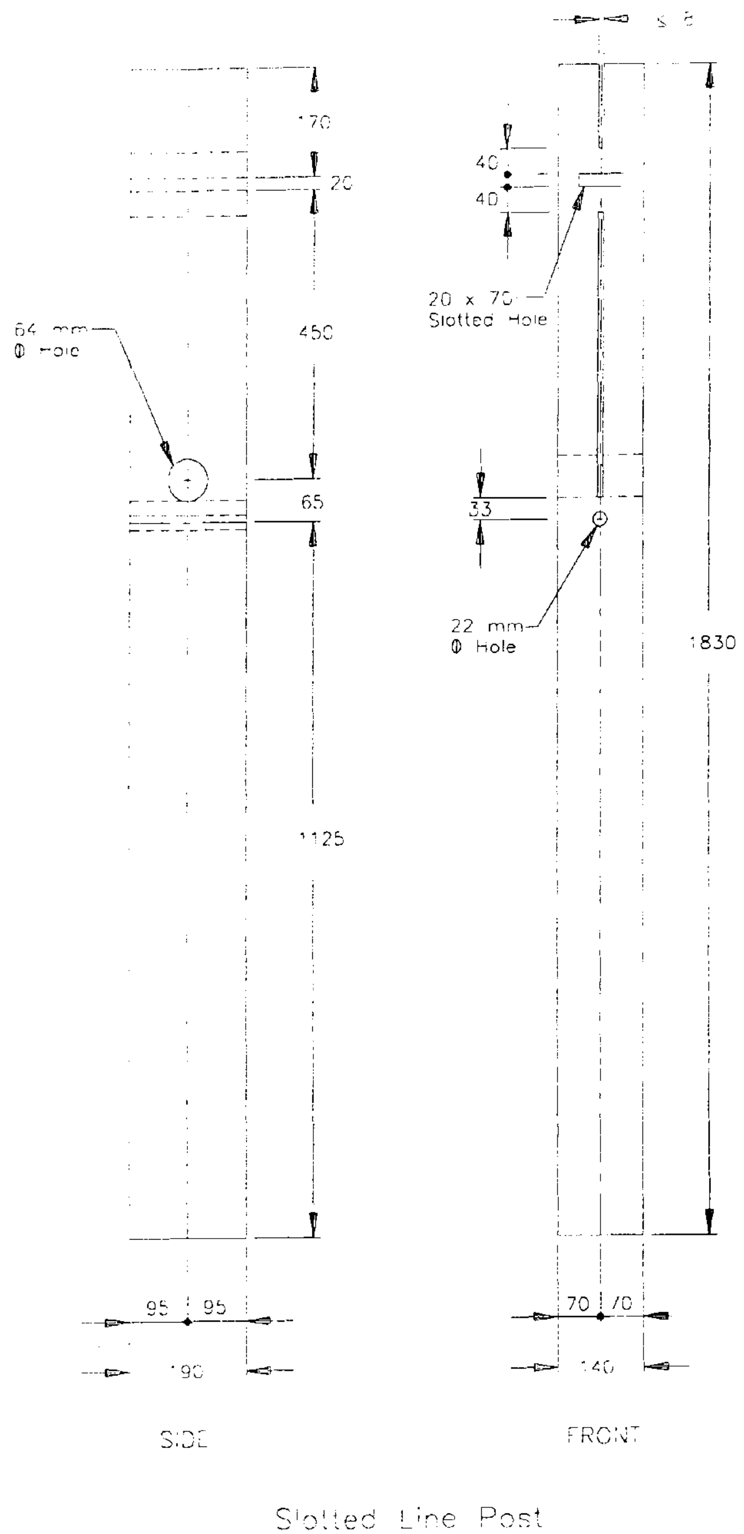


Figure 109. Schematic of the modified MELT line post.

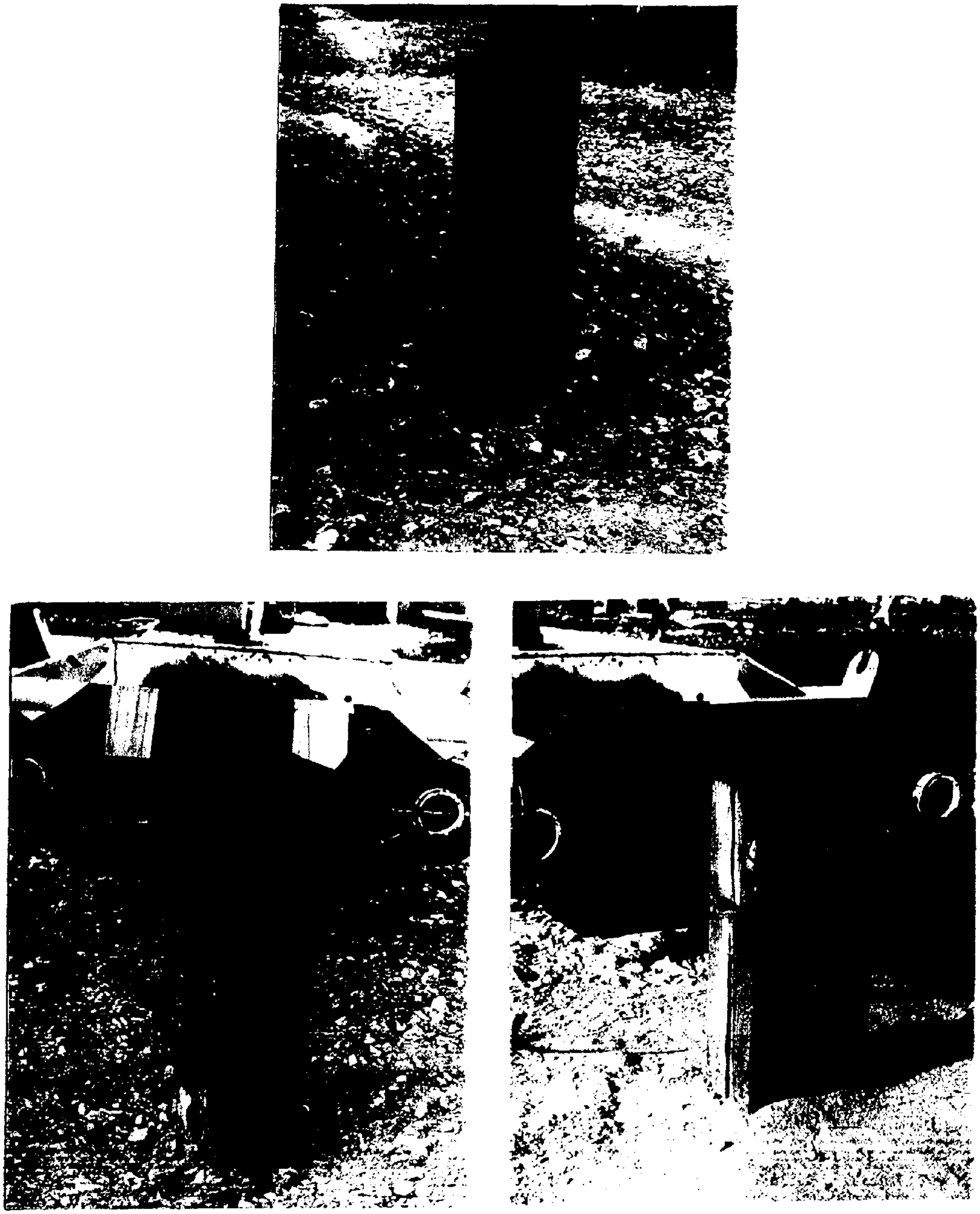


Figure 110. Photographs of test installation for P29 through P31.

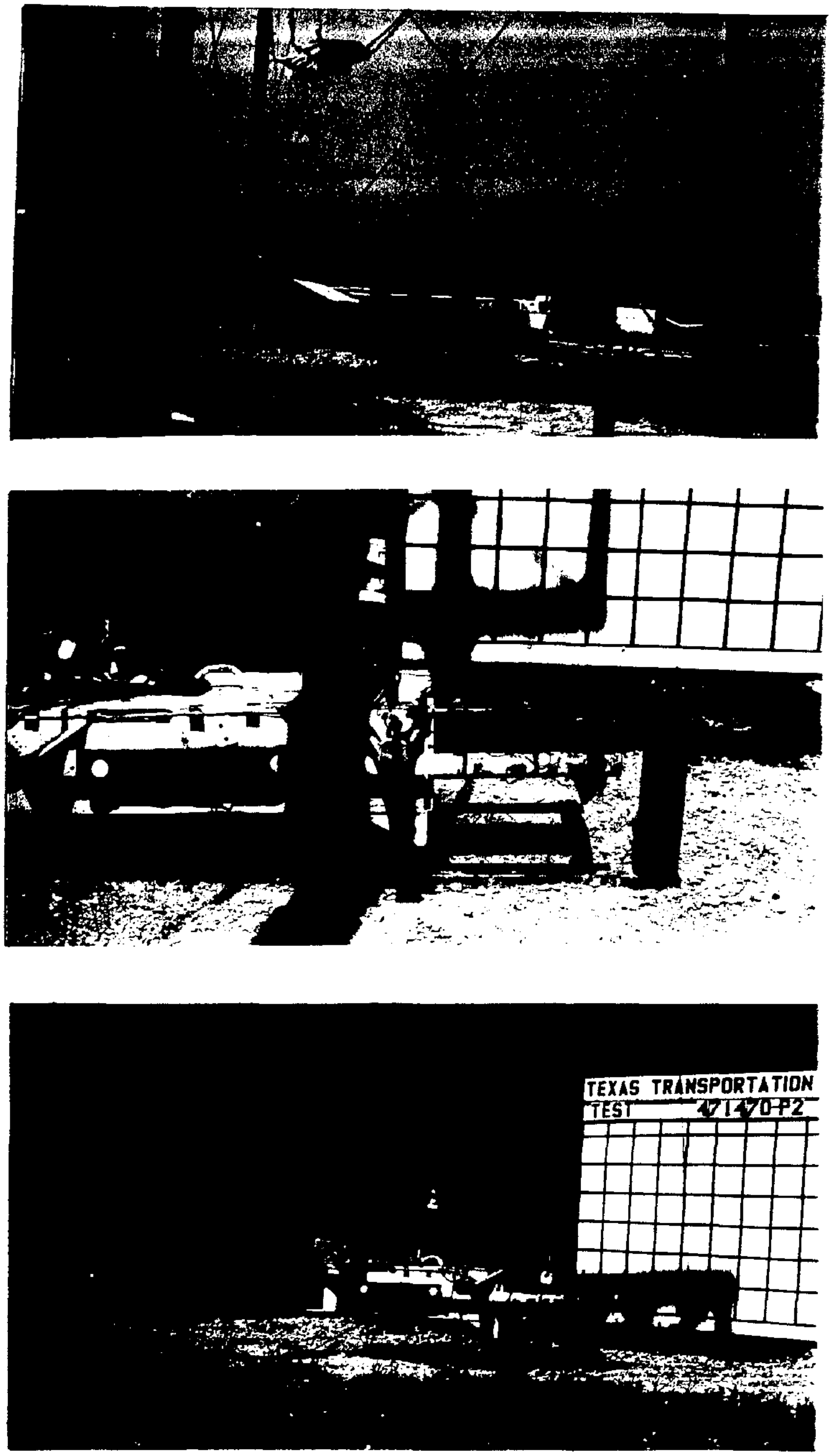


Figure 111. Outdoor pendulum testing facility at Texas Transportation Institute.

of impact was at the apex (bottom) of the swing of the pendulum mass. The impact speed was controlled by the height at which the pendulum mass was released. All the pendulum tests, with the exception of the anchorage test, were conducted at a nominal speed of 35 km/h (21.8 mi/h). For the anchorage test, the maximum drop height, as limited by the length of the cable connecting the pendulum mass to the W-beam rail, was used.

A low-impedance, piezoelectric accelerometer was mounted at the back of the pendulum mass to measure acceleration in the longitudinal direction. A rigid nose was used with the pendulum, and a 38-mm (1-1/2-in) thick rubber pad was attached to the face of the pendulum nose to dampen the effects of ringing on the accelerometer. An impact-actuated contact switch was mounted on the nose of the pendulum to indicate the time of impact with the post. The signals from the contact switch and accelerometer were telemetered to a base receiver station and recorded on magnetic tape for a permanent record. The filtered analog data were digitized and processed on a computer for analysis and presentation.

Photographic coverage for the pendulum tests included two video cameras, one positioned perpendicular to the pendulum and the other at a 45-degree angle. Also, 35-mm still cameras were used to document the test installation before and after each test.

15.2.2 Pendulum Test Results

Table 47 summarizes the maximum 10-ms average force for each of the 31 pendulum tests. For each pendulum test, the following plots were generated from the electronic data:

- Time v. Acceleration,
- Time v. Force,
- Time v. Displacement, and
- Force v. Displacement.

For the anchorage test (test no. P01), the maximum force attained was 147.2 kN (33.1 kips), which is less than the typical capacity of approximately 186.8 kN (42.0 kips) for a breakaway cable anchorage system. The force generated by the pendulum mass, which was limited by the length of the connecting cable, was simply not high enough to test the capacity of the anchorage system. However, both end posts were not broken in the test even though the posts were split along the longitudinal slots. It appears from the test that the modified end posts would have sufficient anchorage capacity. A full-scale redirection test would be required to truly test the adequacy of the breakaway cable anchorage system with the modified end posts.

The modified MELT end posts were tested along the weak axis (test nos. P02 through P04), the strong axis (test nos. P08 through P10), and across the diagonal (test nos. P14 through P16). Standard MELT end posts were also tested under the same configurations (test nos. P05 through P07 for the weak axis, P11 through P13 for the strong axis, and P17

Table 47. Summary of pendulum test results.

Test Article	Test Configuration		Test No.	Max. 10-ms Force	
	Axis	Height, mm (in)		kN	Kips
Anchorage Assembly	N/A	550 (21.7)	P01	147.2	33.1
Modified MELT End Post	Weak	550 (21.7)	P02	18.7	4.2
			P03	16.9	3.8
			P04	28.5	6.4
			Average	21.4	4.8
	Strong	550 (21.7)	P08	42.3	9.5
			P09	67.6	15.2
			P10	44.9	10.1
			Average	51.6	11.6
	Diagonal	550 (21.7)	P14	31.1	7.0
			P15	28.0	6.3
			P16	30.7	6.9
			Average	29.8	6.7
Standard MELT End Post	Weak	550 (21.7)	P05	33.4	7.5
			P06	33.4	7.5
			P07	53.8	12.1
			Average	40.0	9.0
	Strong	550 (21.7)	P11	59.2	13.3
			P12	42.7	9.6
			P13	68.1	15.3
			Average	56.5	12.7
	Diagonal	550 (21.7)	P17	48.0	10.8
			P18	49.8	11.2
			P19	39.1	8.8
			Average	45.8	10.3

Table 47. Summary of pendulum test results (continued).

Test Article	Test Configuration		Test No.	Max. 10-ms Force	
	Axis	Height, mm (in)		kN	Kips
Modified Line Post	Weak	300 (11.8)	P20	32.9	7.4
			021	27.6	6.2
			Average	30.2	6.8
	Strong	550 (21.7)	P24	27.1	6.1
			P25	28.5	6.4
			Average	27.8	6.3
	Diagonal	550 (21.7)	P28	18.7	4.2
			P29	34.3	7.7
			Average	26.5	6.0
Standard CRT Post	Weak	300 (11.8)	P22	57.4	12.7
			P23	30.3	6.7
			Average	43.8	9.7
	Strong	550 (21.7)	P26	34.3	7.6
			P27	55.6	12.3
			Average	45.0	10.0
	Diagonal	550 (21.7)	P30	24.5	5.5
			P31	36.5	8.2
			Average	30.5	6.9

through P19 for the diagonal) for comparison purposes. The modified MELT end posts exhibited characteristics in accordance with the intended design (i.e., lower forces along the weak axis and across the diagonal and comparable forces along the strong axis).

The maximum 10-ms forces for the modified MELT end posts (tests nos. P02-P04) averaged 21.4 kN (4.8 kips), which was almost 50 percent lower than the average for the standard MELT end posts (test nos. P05-P07) at 40.0 kN (9.0 kips). The peak 10-msec average forces for the modified MELT end posts (test nos. P08-P10) of 51.6 kN (11.6 kips) was only slightly lower than that of the standard MELT end posts (test nos. P11-P13) at 56.5 kN (12.7 kips). For impacts across the diagonals of the posts, the average maximum 10-ms average forces for the modified MELT end posts (test nos. P14-P16) was approximately one-third lower at 29.8 kN (6.7 kips) than that of the standard MELT end posts (test nos. P17-P19) at 45.8 kN (10.3 kips).

As in the case of the modified MELT end post, the average maximum 10-ms force for the modified line posts along the weak axis was considerably lower than that of the standard CRT posts. The average maximum 10-ms force for the modified line posts along the weak axis (tests nos. P20 and P21) was 30.2 kN (6.8 kips) versus 43.8 kN (9.7 kips) for the standard CRT posts (test nos. P22 and P23). However, the peak 10-ms average force for the modified line posts (test nos. P24 and P25) was also considerably lower than that of the standard CRT posts (test nos. P26 and P27) for the strong axis, 27.8 kN (6.3 kips) versus 45.0 kN (10.0 kips), respectively. For the diagonal direction, the peak 10-msec average force for the modified line posts (test nos. P28 and P29) was slightly lower at 26.5 kN (6.0 kips) than that of the standard CRT posts (test nos. P30 and P31) at 30.5 kN (6.9 kips). It should be noted that there were considerable variations in the maximum 10-ms forces for tests with the standard CRT posts.

15.3 SUMMARY OF FINDINGS

Based on the results of these laboratory tests, FHWA decided that the optimal dimensions are 40 mm (1.6 in) for both the length between the bottom of the top longitudinal slot to the top of the post bolt slot and between the bottom of the post bolt slot to the top of the second longitudinal slot. This provides a total length of 80 mm (3.2 in) for the plug, which is slightly higher than the combined length of 75 mm (3.0 in) for the configuration of 25 mm (1.0 in) between the bottom of the top longitudinal slot to the top of the post bolt slot and 50 mm (2.0 in) between the bottom of the post bolt slot to the top of the second longitudinal slot.

Results of pendulum tests indicate that the modified MELT end post is substantially weaker along the weak axis and across the diagonal than the standard MELT end post. On the other hand, the modified MELT end post appear to have comparable strength to that of the standard MELT end post along the strong axis. These are desirable characteristics since the post would break away more readily in end-on impacts while maintaining similar lateral stiffness to resist redirectional impacts. The anchorage test with the modified MELT end posts did not generate forces near the capacity of the breakaway cable anchorage system. However, it appears that the modified MELT end posts would have sufficient anchorage capacity. Thus, the modified MELT end post appears to satisfy its design objectives and is recommended for potential use with the modified MELT.

For the modified line post, results of the pendulum tests indicate that the modified line post is weaker than the standard CRT post in all three directions of impact. The lower forces along the weak axis and across the diagonal for the modified line posts are desirable in that the post would break away more readily in end-on impacts. However, the lower force for the modified line post along the strong axis is not desirable since the posts could break away prematurely in redirectional impacts, which in turn could adversely affect the structural adequacy of the terminal. Thus, the replacement of standard CRT posts with modified line posts is not recommended without additional testing and analysis.

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