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16. Abstract <p>The objective of this study is to crash test and evaluate the existing Wyoming bridge railing design in accordance with guidelines set forth in NCHRP Report 350 for test level 3 (TL-3) conditions. One crash test with a 2000-kg pickup truck (test designation 3-11) at a nominal impact speed and angle of 100 km/h and 25 degrees was conducted. The other required test with an 820-kg passenger car (test designation 3-10) at a nominal impact speed and angle of 100 km/h and 20 degrees was deemed not necessary since an identical test was previously conducted with successful results when the bridge railing system was evaluated under NCHRP Report 230 guidelines.</p> <p>Results of the pickup truck redirection test was presented in this report. The bridge railing contained and smoothly redirected the impacting vehicle. The vehicle did not penetrate or go over the bridge railing. There were no detached elements or debris to show potential for penetrating the occupant compartment or to present undue hazard to others in the area. Damage sustained by the vehicle was considered moderate given the severe nature of the impact conditions. Maximum deformation of the occupant compartment was 92 mm in the firewall area and was judged not to cause serious injury. The vehicle remained upright during and after the collision. The exit angle at loss of contact with the bridge railing was 9.2 degrees which was less than 60 percent of the test impact angle. Minimal, if any, intrusion into the adjacent traffic lanes was caused by the vehicle exit trajectory. The occupant risk factors were well within the preferred limits specified in NCHRP Report 350.</p> <p>In summary, the existing Wyoming bridge railing system was judged to have met all the evaluation criteria set forth in NCHRP Report 350 for test level 3 (TL-3) conditions.</p>					
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH					LENGTH				
in	inches	25.4	millimeters	mm	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	km	kilometers	0.621	miles	mi
AREA					AREA				
in ²	square inches	645.2	square millimeters	mm ²	mm ²	square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	m ²	square meters	1.195	square yards	yd ²
ac	acres	0.405	hectares	ha	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	km ²	square kilometers	0.386	square miles	mi ²
VOLUME					VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	L	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	m ³	cubic meters	35.71	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	m ³	cubic meters	1.307	cubic yards	yd ³
NOTE: Volumes greater than 1000 l shall be shown in m ³ .									
MASS					MASS				
oz	ounces	28.35	grams	g	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kg	kilograms	2.202	pounds	lb
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")	Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)					TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C	°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION					ILLUMINATION				
fc	foot-candles	10.76	lux	lx	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS					FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N	N	newtons	0.225	poundforce	lbf
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa	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

The Wyoming Department of Transportation (WYDOT) has an existing bridge railing system (herein referred to as the 740WYBRAIL) that was successfully crash tested in accordance with procedures outlined in National Cooperative Highway Research Program (NCHRP) Report 230.^(1,2) Since that time, the Federal Highway Administration (FHWA) has adopted NCHRP Report 350 as the official guideline for evaluating the crashworthiness of roadside safety features.⁽³⁾ The FHWA has also required that all new installations of roadside safety features on the National Highway System (NHS) after September of 1998 will be only those that have successfully met the testing and evaluation criteria of NCHRP Report 350. Thus, while the 740WYBRAIL system has satisfied the requirements of NCHRP Report 230, it becomes necessary to crash test and evaluate the safety performance of the existing 740WYBRAIL bridge rail system under the new guidelines.

The WYDOT decided to crash test the existing 740WYBRAIL bridge rail system under test level three (TL-3) conditions. According to NCHRP Report 350 guidelines, two crash tests are required for evaluating the length-of-need (LON) section of a bridge railing design under TL-3 test conditions; one with an 820-kg passenger car and one with the 2000-kg pickup truck. Since the 740WYBRAIL bridge railing system has previously been crash tested with successful results under guidelines set forth in NCHRP Report 230, the test with the 820-kg passenger is deemed not necessary since the test vehicle and test conditions are unchanged in NCHRP Report 350. The only required crash test is therefore the pickup truck test.

This report presents the results of the full-scale crash test with the pickup truck performed on the existing Wyoming 740WYBRAIL bridge railing system under TL-3 test conditions.

II. STUDY APPROACH

2.1 BRIDGE RAILING DESIGN DETAILS

The existing 740WYBRAIL bridge railing system is a post-and-rail design, details of which are shown in figure 1. The overall height of the bridge rail is 740 mm, including a 150 mm high, 500 mm wide concrete curb. The posts were fabricated from two 16-mm thick steel plates with nominal dimensions of 574 mm tall x 260 mm wide, spaced 200 mm apart (outside to outside) and welded to a 370 mm x 290 mm x 16 mm thick base plate. The posts are attached to the concrete curb section by three cast-in-place 22-mm diameter high strength steel anchor bolts. The maximum allowable spacing between adjacent posts is 3 m. There are two horizontal rail elements fabricated from TS 152 mm x 51 mm x 6.4 mm structural steel. The rail elements are attached to the posts with 12 mm diameter U-bolts, 80 mm wide and 90 mm long. The face of the rail elements are flush with the face of the curb. A minimum yield stress of 250 Mpa is specified for the steel posts and rail elements. Details of the bridge deck and curb section are shown in figure 2. Minimum yield strengths of 400 Mpa is specified for the steel reinforcement and 26 Mpa for the concrete.

2.2 TEST ARTICLE

A 23-m long test installation was constructed in accordance with standard bridge specifications used by the Wyoming Department of Transportation, including steel reinforcement and anchorage details. The test installation consisted of a 1 m wide, 200 mm thick cantilevered concrete simulated bridge deck, with a 500 mm wide and 150 mm high concrete curb. The maximum post spacing of 3 m was used since it represents the most critical condition. Photographs of the completed 740WYBRAIL installation are presented in figure 3.

2.3 CRASH TEST MATRIX

According to guidelines set forth in NCHRP Report 350, the following two crash tests are required for evaluating the length-of-need (LON) section of a bridge railing design under the TL-3 test conditions:

1. Test designation 3-10. A 820-kg passenger car impacting the LON section of the bridge railing at a nominal speed and angle of 100 km/h and 20 degrees. The purpose of the small car test is to evaluate the overall performance of the LON section in general, and occupant risks in particular.
2. Test designation 3-11. A 2000-kg pickup truck impacting the LON section of the bridge railing at a nominal speed and angle of 100 km/h and 25 degrees. The purpose of this test is to evaluate the strength of the LON section in containing and redirecting the 2000P vehicle.

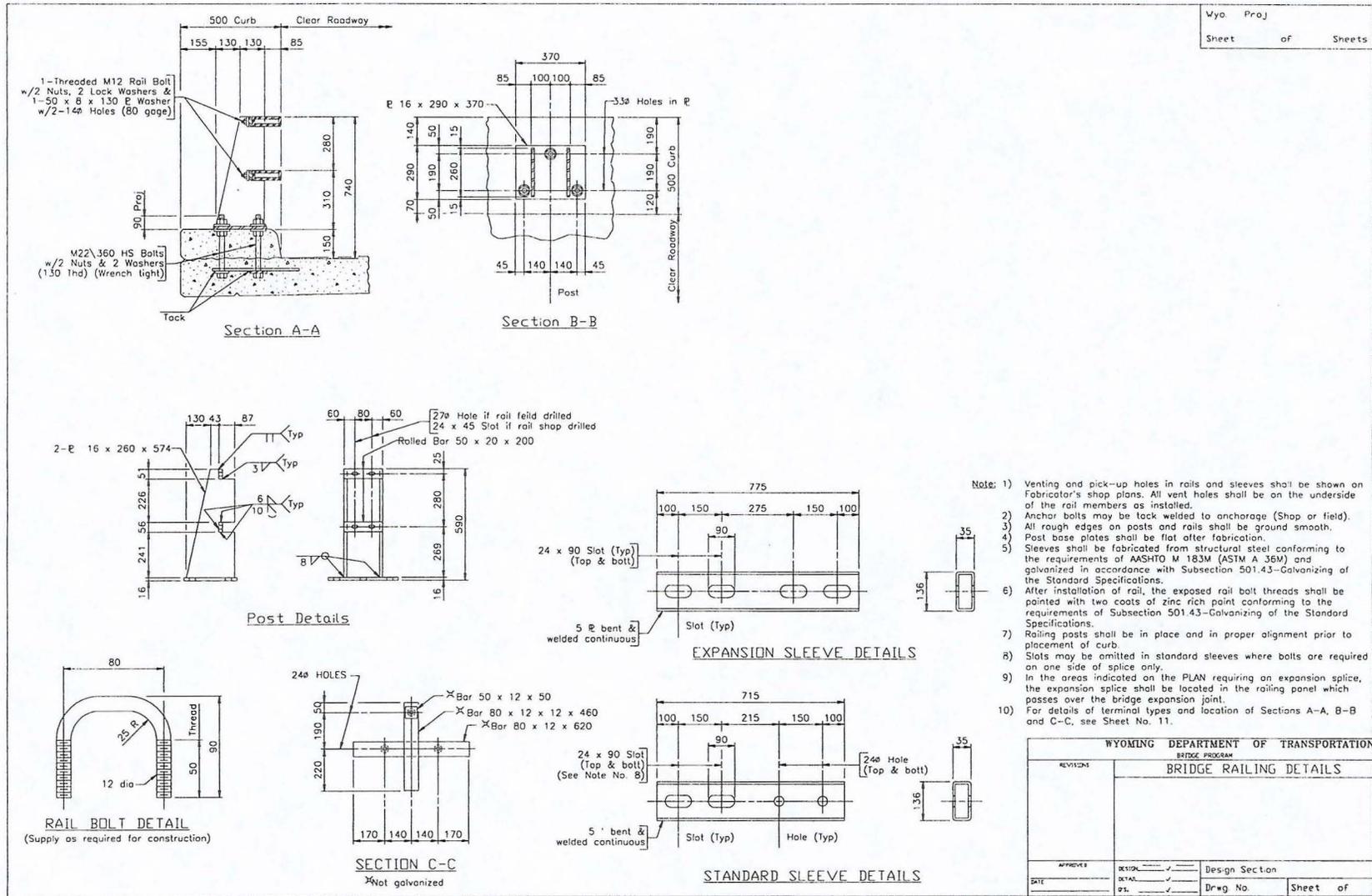


Figure 1. Details of the Wyoming 740WYBRIL bridge railing design.

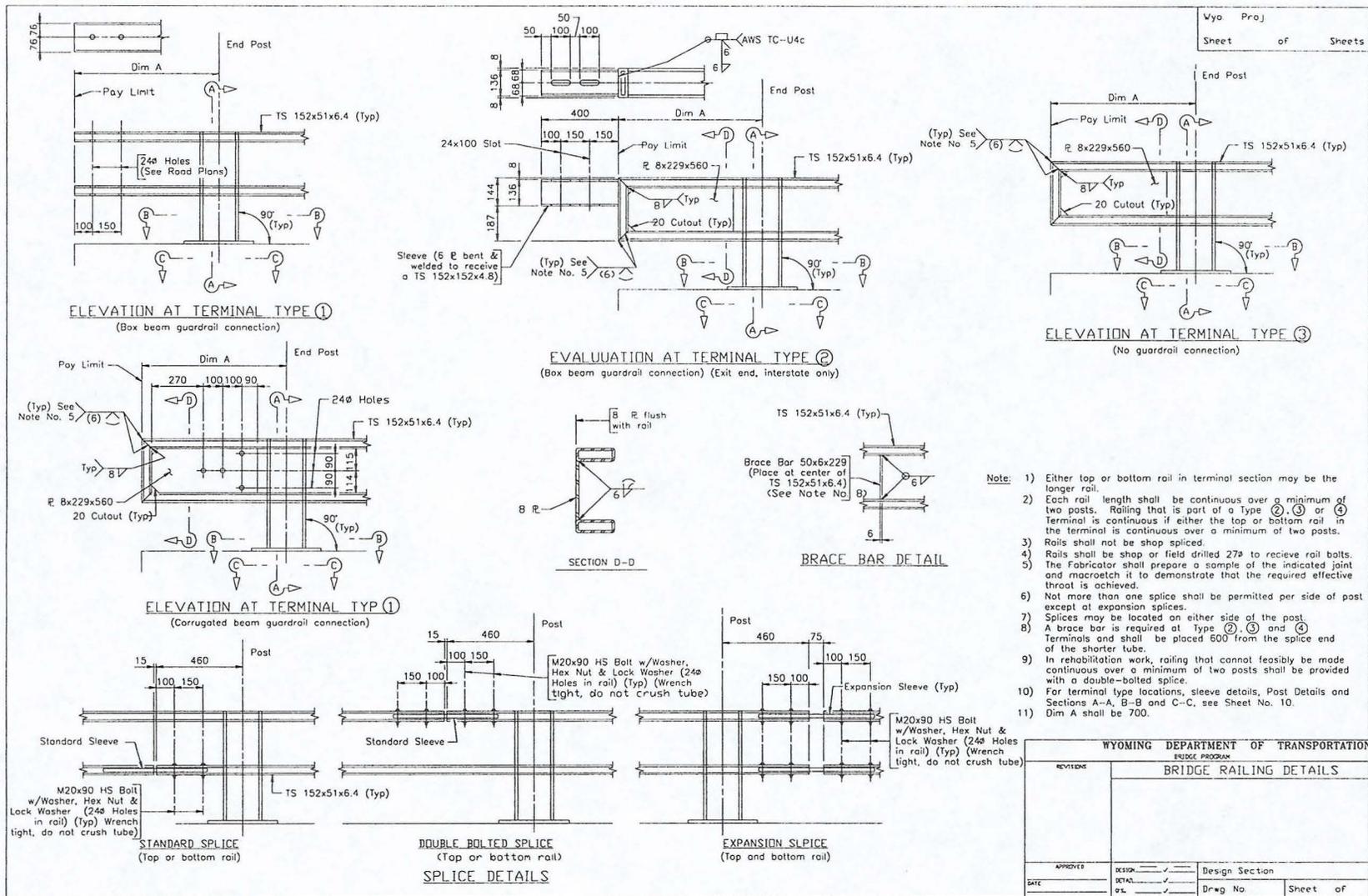


Figure 2. Details of the Wyoming 740WYBRAIL bridge railing elements.

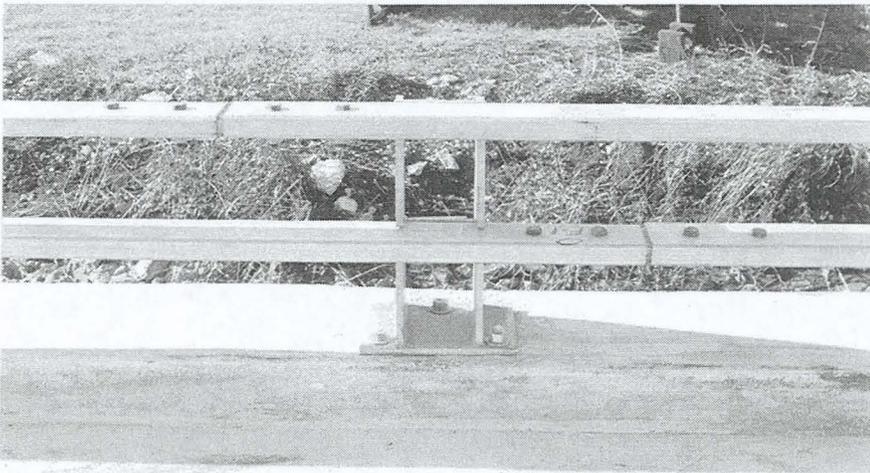
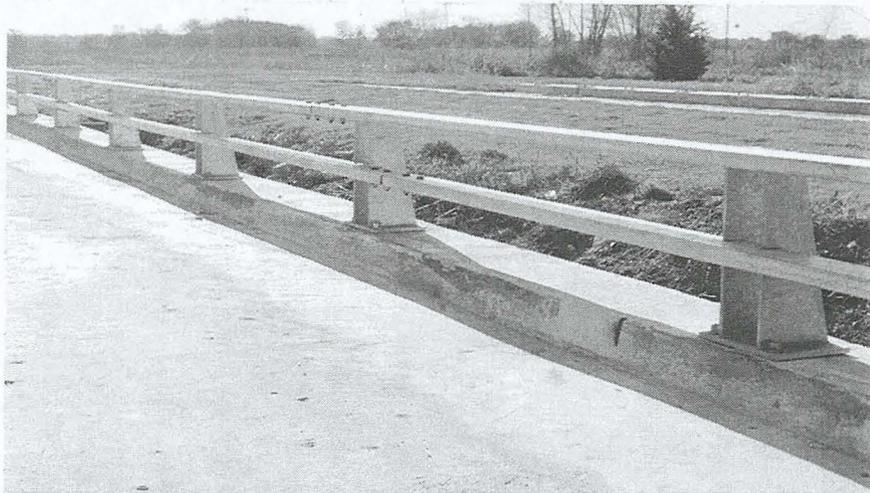


Figure 3. Wyoming 740WYBRAIL installation before test 472610-4.

As mentioned previously, since the 740WYBRAIL bridge railing system has been successfully crash tested under the guidelines set forth in NCHRP Report 230, test designation 3-10 is deemed not necessary since the test vehicle and test conditions are unchanged in NCHRP Report 350. Test designation 3-11 was the only crash test required.

2.4 EVALUATION CRITERIA

The crash test performed was evaluated in accordance with the criteria presented in NCHRP Report 350. As stated in NCHRP Report 350, "Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision." Accordingly, the following safety evaluation criteria from table 5.1 of NCHRP Report 350 were used to evaluate the crash test reported herein:

- **Structural Adequacy**
 - A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable.
- **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. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
 - F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.
- **Vehicle Trajectory**
 - K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
 - 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.
 - M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.

2.5 CRASH TEST AND DATA ANALYSIS PROCEDURES

The crash test and data analysis procedures were in accordance with guidelines presented in NCHRP Report 350. Brief descriptions of these procedures are presented as follows.

2.5.1 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 to measure longitudinal, lateral, and vertical acceleration levels, and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. The accelerometers were strain gage 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 installation.

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/compartiment impact velocities, time of occupant/compartiment impact after vehicle impact, and the highest 10-ms 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 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers were then filtered with a 60 Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions were plotted using a commercially available software package (QUATTRO PRO).

The PLOTANGLE program used the digitized data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.00067-second intervals and then instructs a plotter to draw a reproducible plot: yaw, pitch, and roll versus time. These

displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at initial impact.

2.4.2 Anthropomorphic Dummy Instrumentation

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, placed in the driver's position is required in tests with the 820C vehicle. Use of a dummy in the 2000P vehicle is optional according to NCHRP Report 350 and there was no dummy used in this test with the 2000P vehicle.

2.4.3 Photographic Instrumentation and Data Processing

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; and one placed behind the installation at an angle; a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the installation 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 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.

2.4.4 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. A 2 to 1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or braking inputs, until the vehicle cleared the immediate area of the test site, at which time brakes on the vehicle were activated to bring the vehicle to a safe and controlled stop.

III. CRASH TEST RESULTS

As mentioned previously, only the pickup truck redirection test (NCHRP Report 350 test designation 3-11) was deemed necessary to evaluate the safety performance of the existing 740WYBRAIL bridge railing system. Results of this crash test are presented in the following sections.

3.1 PICKUP TRUCK REDIRECTION TEST (TEST NO. 472610-4)

A 1989 Chevrolet 2500 pickup truck, shown in figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2000 kg. The height to the lower edge of the vehicle bumper was 440 mm and it was 670 mm to the upper edge of the bumper. Additional dimensions and information on the vehicle are given in figure 6. The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

3.1.1 Test Description

The vehicle impacted the 740WYBRAIL test installation 1.9 m upstream of post 3, traveling at a speed and angle of 101.7 km/h and 25.2 degrees. At 0.036 second after impact, the right front tire aired out and, at 0.047 second, the vehicle began to redirect. The front of the vehicle contacted post 3 at 0.060 second and the left front tire lost contact with the ground at 0.100 second. At 0.168 second, the left rear tire lost contact with the ground and, at 0.184 second, the front of the vehicle contacted post 4. The vehicle became parallel with the bridge railing at 0.301 second, traveling at a speed of 80.2 km/h. At 0.327 second, the front of the vehicle contacted post 5. The vehicle lost contact with the bridge railing at 0.624 second and was traveling at a speed approximately 65.5 km/h and at an exit angle of 9.2 degrees. Brakes on the vehicle were applied at 1.45 seconds, the vehicle spun counterclockwise 180 degrees and subsequently came to rest facing toward the installation 52.7 m down from the point of impact and 3.7 m toward the traffic lanes. Sequential photographs of the test period are shown in figures 7 and 8.

3.1.2 Damage to Test Installation

Most of the damage to the 740WYBRAIL bridge railing was near post 3 as shown in figures 9 through 11. The base plate at post 3 was moved back and laterally 6 mm and a crack in the curb radiated out from the right rear anchor bolt. Both flanges on post 3 were bent. The maximum permanent deformations were 16 mm for the top rail element and 51 mm for the bottom rail element. Total length of contact of the vehicle with the rail elements was 2.7 m and the total length of contact with the curb was 3.7 m.

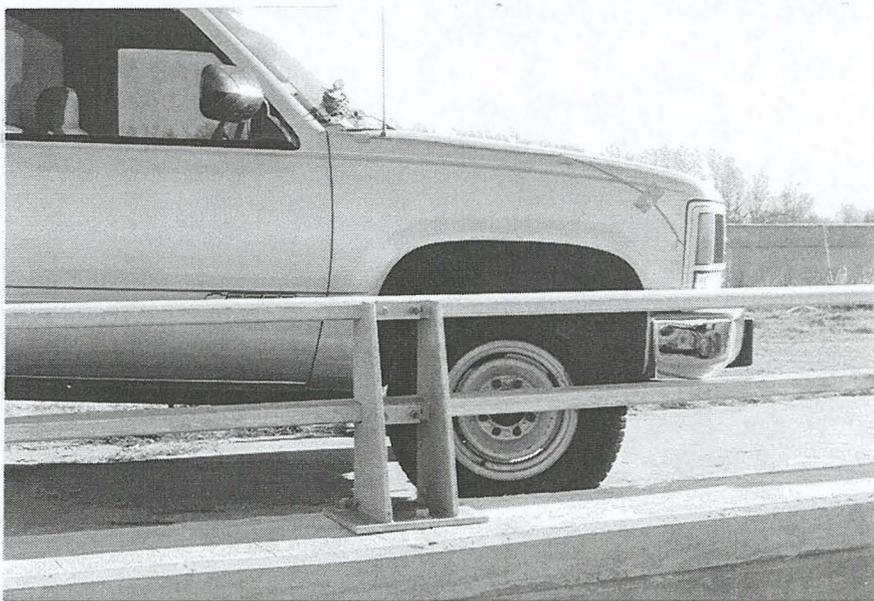


Figure 4. Vehicle/installation geometrics for test 472610-4.



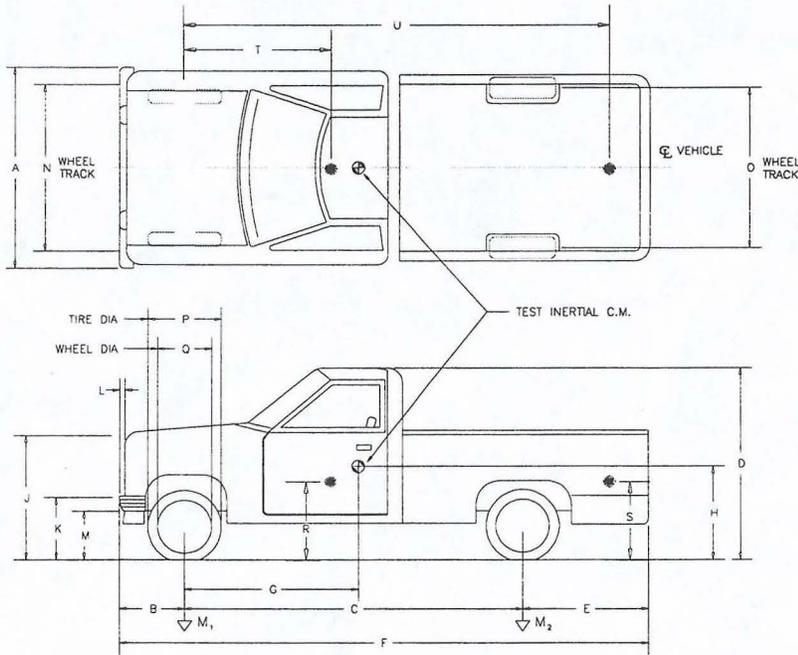
Figure 5. Vehicle before test 472610-4.

DATE: 02/12/96 TEST NO.: 472610-4 VIN NO.: 1GCGC24K5KE215196
 YEAR: 1989 MAKE: Chevrolet MODEL: 2500 pickup
 TIRE INFLATION PRESSURE: _____ ODOMETER: 213403 TIRE SIZE: 245 75R16

MASS DISTRIBUTION (kg) LF 540 RF 544 LR 457 RR 459

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Crack in windshield (marked)



● Denotes accelerometer location.

NOTES: Rear 90 mm to left

ENGINE TYPE: 8 cylinder

ENGINE SIZE: 5.7 liter

TRANSMISSION TYPE:

AUTO

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: No dummy

MASS: _____

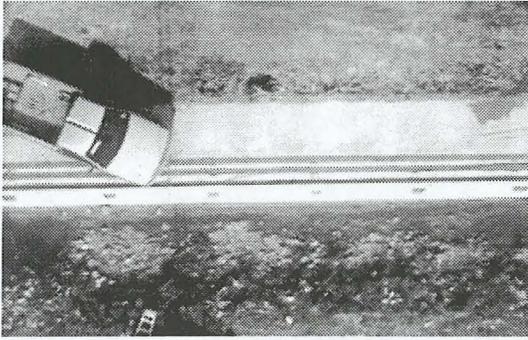
SEAT POSITION: _____

GEOMETRY - (mm)

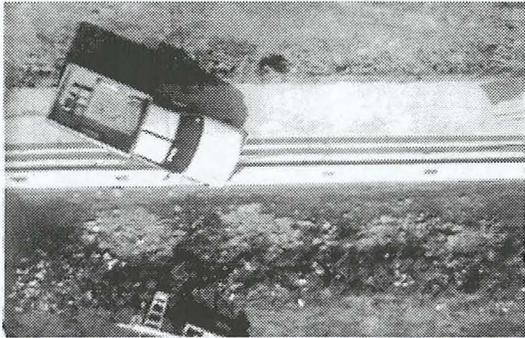
A	<u>1870</u>	E	<u>1320</u>	J	<u>1070</u>	N	<u>1595</u>	R	<u>740</u>
B	<u>780</u>	F	<u>5440</u>	K	<u>670</u>	O	<u>1620</u>	S	<u>940</u>
C	<u>3340</u>	G	<u>1529.7</u>	L	<u>75</u>	P	<u>760</u>	T	<u>1500</u>
D	<u>1840</u>	H	_____	M	<u>440</u>	Q	<u>440</u>	U	<u>4060</u>

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M ₁	<u>1163</u>	<u>1084</u>	_____
M ₂	<u>917</u>	<u>916</u>	_____
M _T	<u>2080</u>	<u>2000</u>	_____

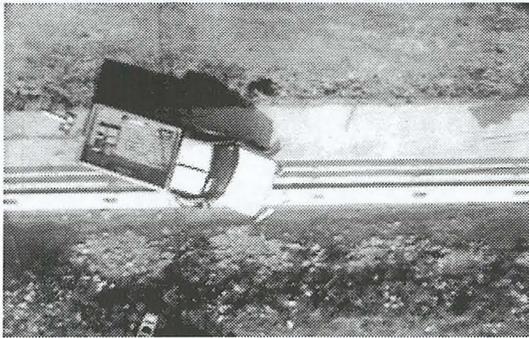
Figure 6. Vehicle properties for test 472610-4.



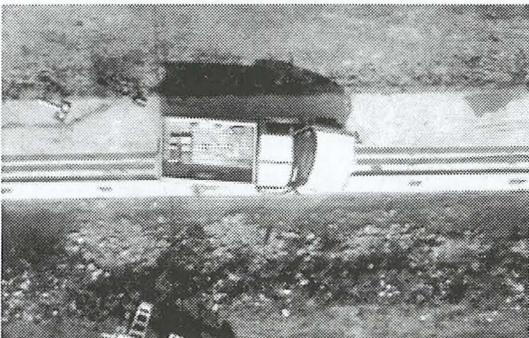
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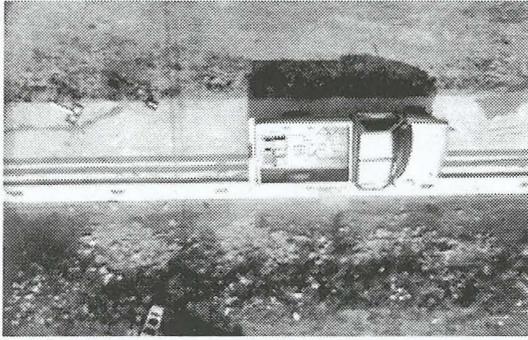


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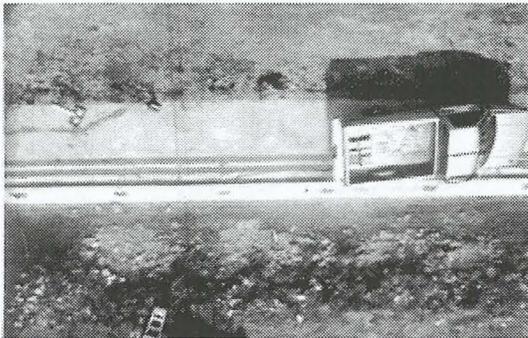


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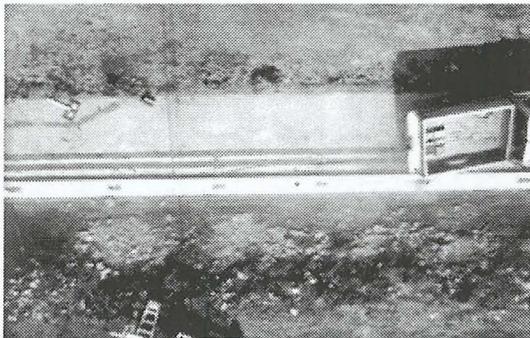
Figure 7. Sequential photographs for test 472610-4 (overhead and frontal views).



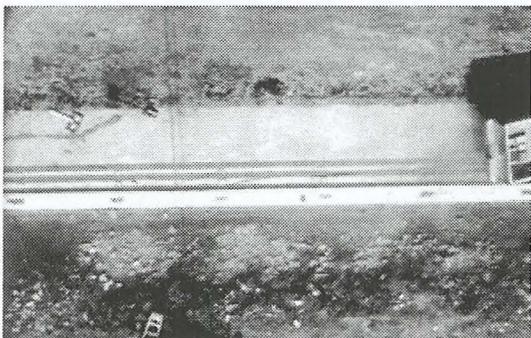
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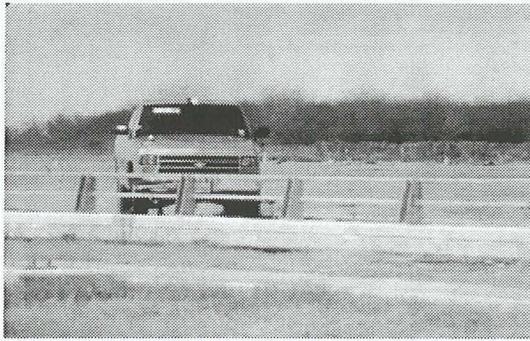
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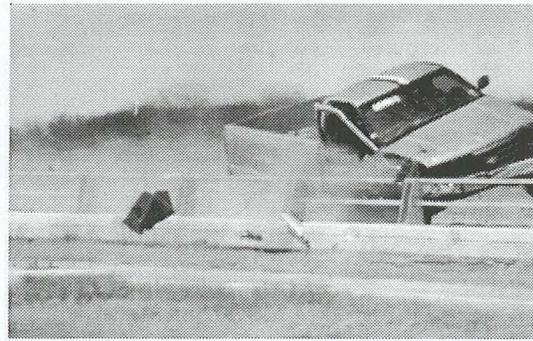
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Figure 7. Sequential photographs for test 472610-4
(overhead and frontal views) (continued).



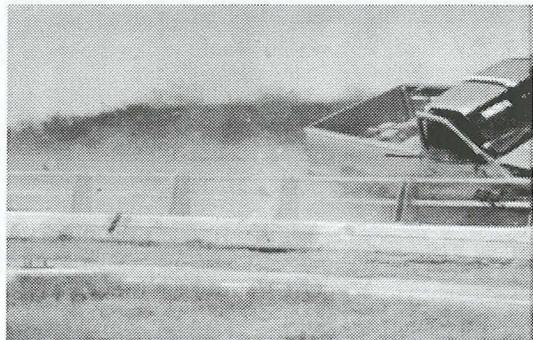
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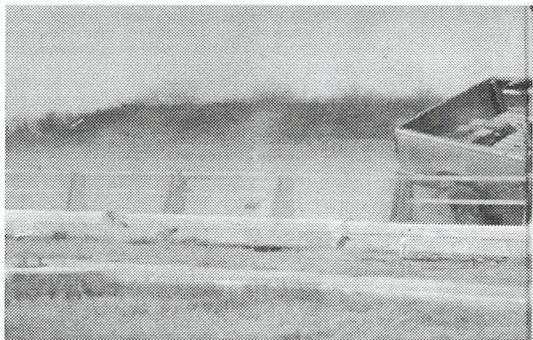
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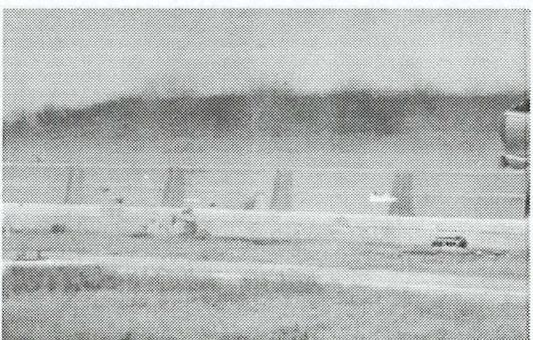
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0.229 s



0.673 s

Figure 8. Sequential photographs for test 472610-4 (rear view).

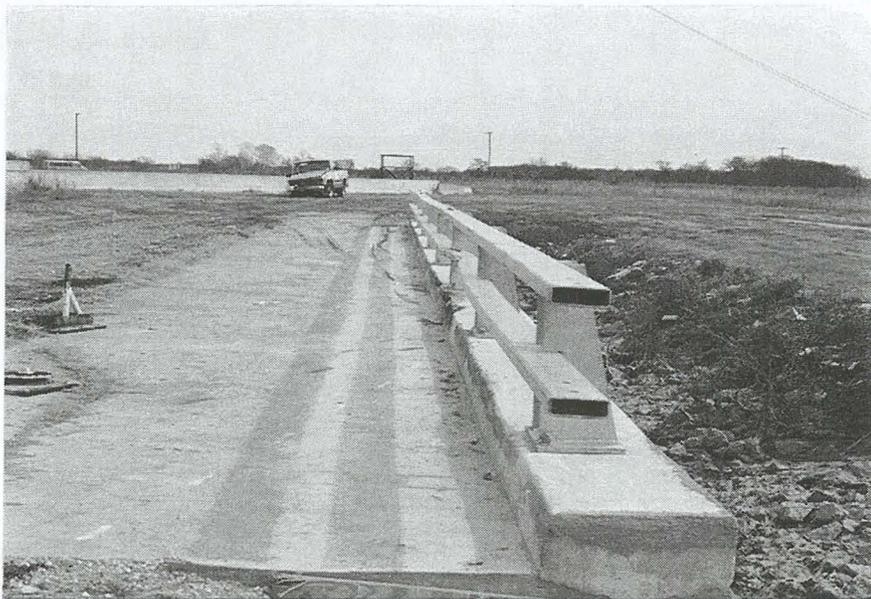
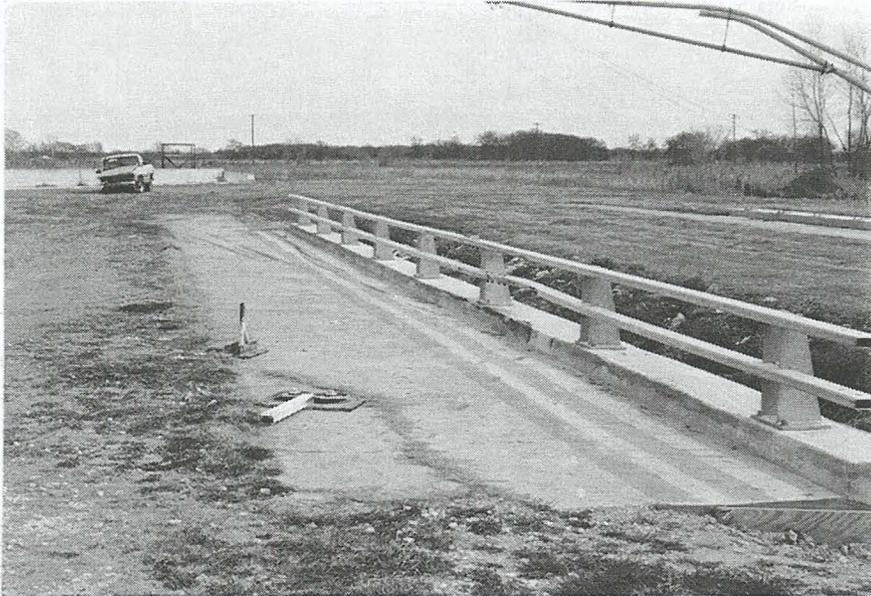


Figure 9. After impact trajectory for test 472610-4.

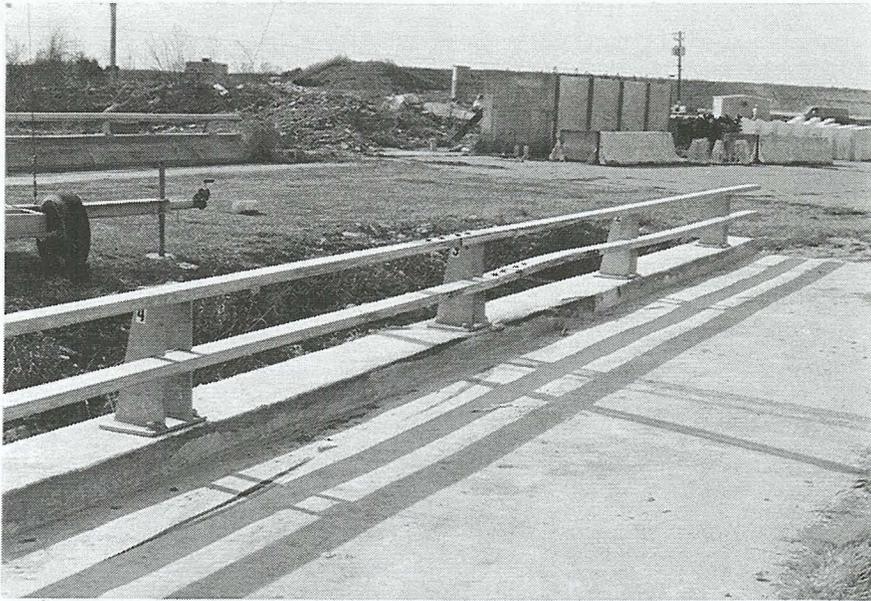


Figure 10. Installation after test 472610-4.

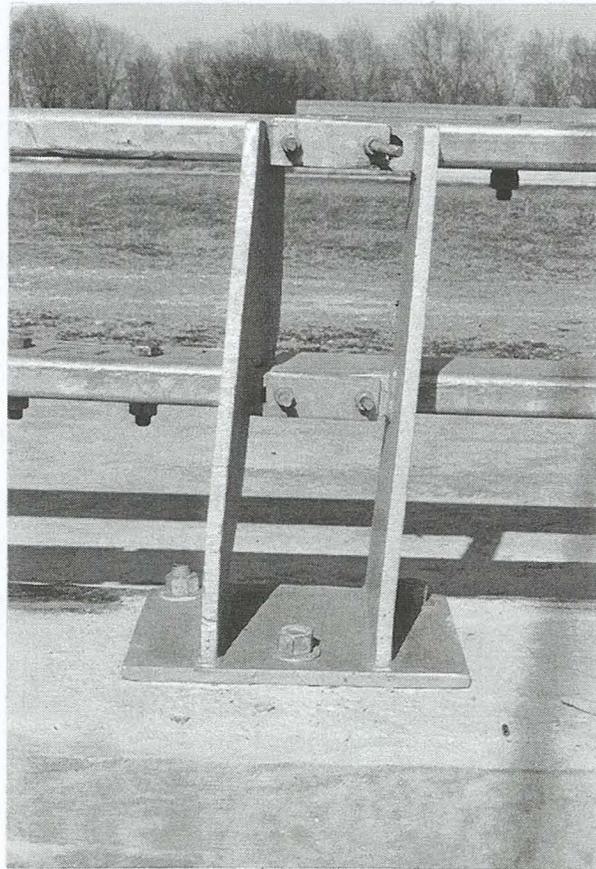
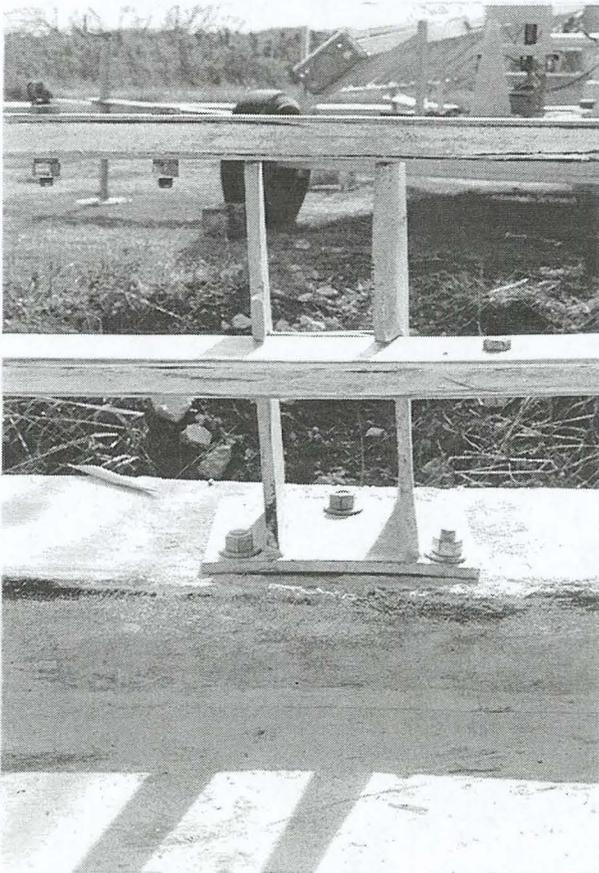
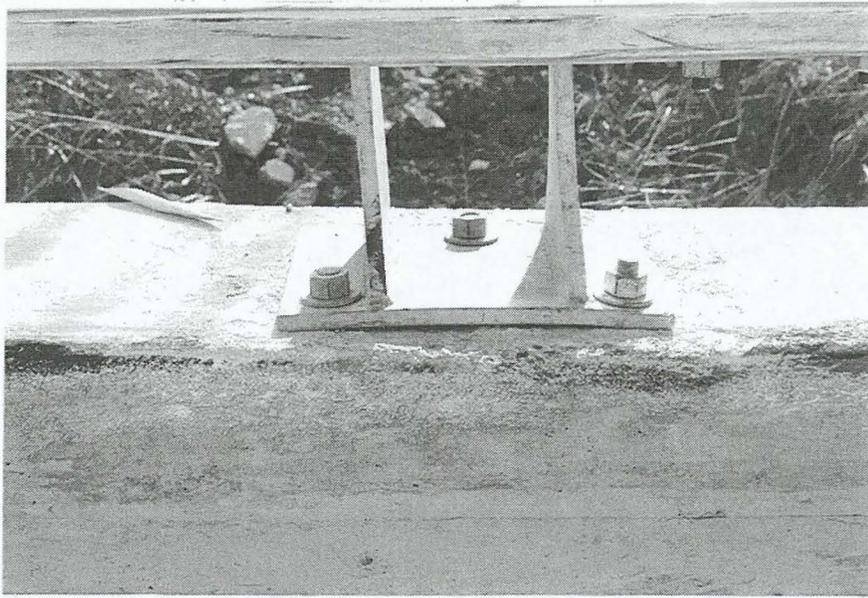


Figure 11. Damage at post 3 after test 472610-4.

3.1.3 Vehicle Damage

Damage to the vehicle is shown in figures 12 and 13. The right side upper and lower A-arms, sway bar, frame, and floorpan were bent. The front bumper, grill, fan, radiator, hood, both front quarter panels, right door, and both right side tires and rims were damaged. The windshield was shattered and right door glass was broken out. Maximum crush to the exterior of the vehicle was 960 mm at the right front corner. The maximum deformation of the occupant compartment was 92 mm in the center front firewall area.

3.1.4 Occupant Risk Values

Due to damage sustained by the vehicle near the location where the accelerometers at the vehicle center of gravity was mounted, it was felt that the data from these accelerometers might be unreliable. Therefore, data from the backup accelerometers located over the rear axle, extrapolated to the center of gravity, were used instead. The occupant risk factors were computed as follows. In the longitudinal direction, the occupant impact velocity was 7.6 m/s at 0.160 second, the highest 0.010-second occupant ridedown acceleration was 4.6 g from 0.188 to 0.198 second, and the maximum 0.050-second average acceleration -9.2 g between 0.055 and 0.105 second. In the lateral direction, the occupant impact velocity was 7.7 m/s at 0.133 second, the highest 0.010-second occupant ridedown acceleration was -12.8 g from 0.180 to 0.190 second, and the maximum 0.050-second average was -12.1 g between 0.054 and 0.104 second. These data and other pertinent information from the test are summarized in figure 14. Vehicle angular displacements are displayed in figure 15. Vehicular accelerations versus time traces from the extrapolated data are presented in figure 16 and 17.



Figure 12. Vehicle after test 472610-4.

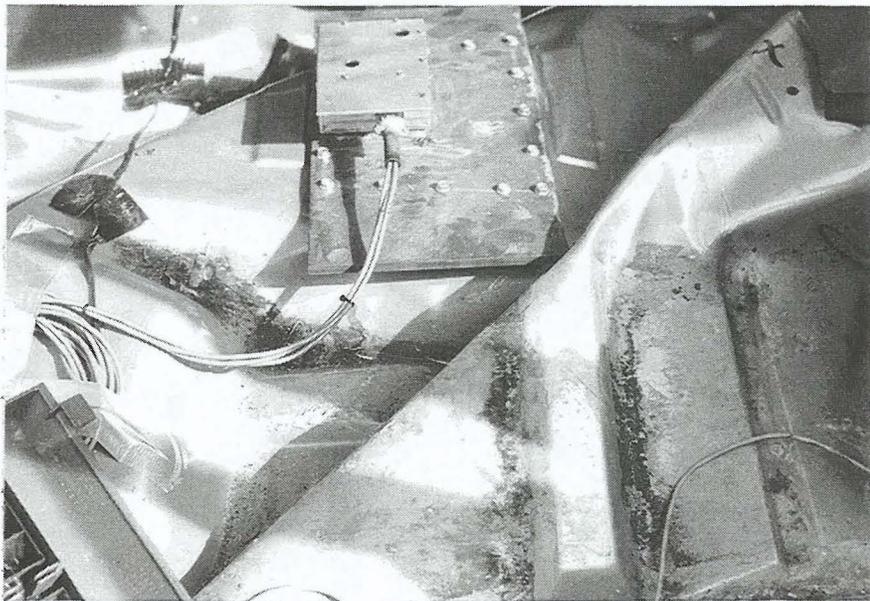
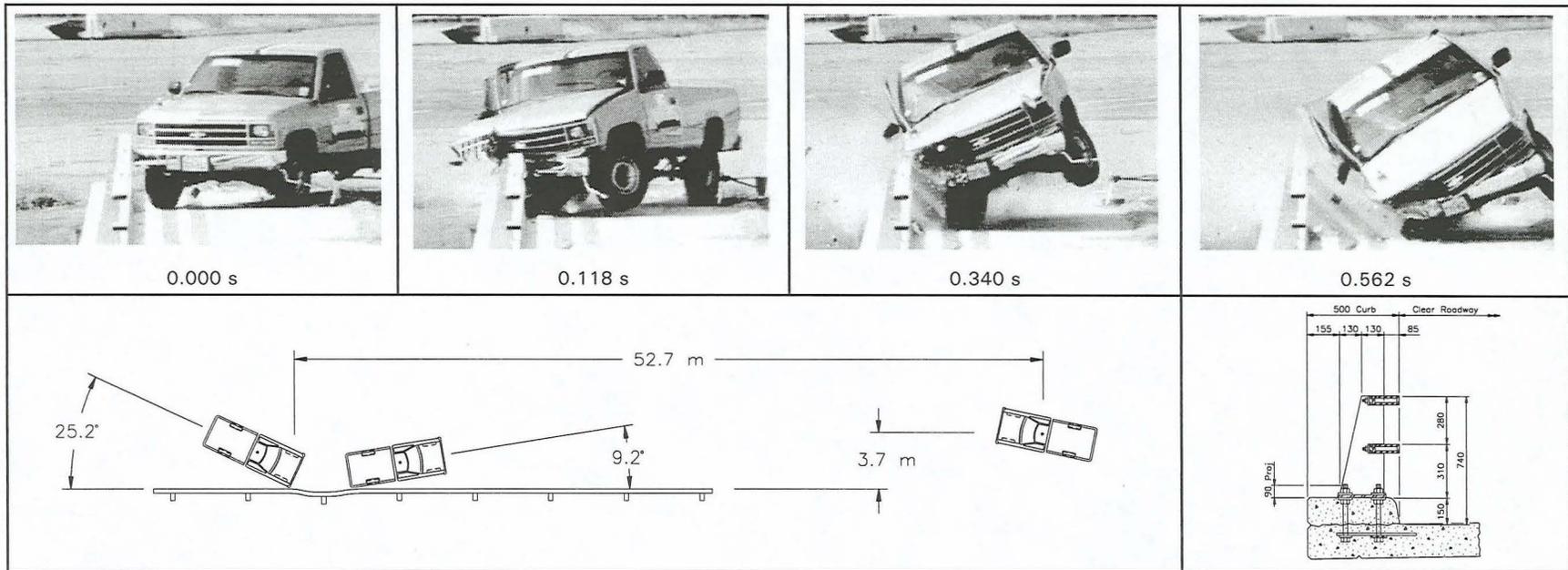


Figure 13. Interior of vehicle after test 472610-4.



General Information

Test Agency Texas Transportation Institute
 Test No. 472610-4
 Date 02/12/96
Test Article
 Type Bridge Rail
 Name 740WYBRAIL
 Installation Length (m) 23
 Size and/or dimension
 and material of key Tubular steel railing on
 elements concrete deck and curb
 Soil Type and Condition Concrete bridge deck, dry
Test Vehicle
 Type Production
 Designation 2000P
 Model 1989 Chevrolet 2500
 Mass (kg) Curb 2080
 Test Inertial 2000
 Dummy No dummy
 Gross Static 2000

Impact Conditions

Speed (km/h) 101.7
 Angle (deg) 25.2
Exit Conditions
 Speed (km/h) 65.5
 Angle (deg) 9.2
Occupant Risk Values
 Impact Velocity (m/s)
 x-direction 7.6
 y-direction 7.7
 THIV (optional)
Ridedown Accelerations (g's)
 x-direction 4.6
 y-direction -12.8
 PHD (optional)
 ASI (optional)
 Max. 0.050-s Average (g's)
 x-direction -9.2
 y-direction -12.1
 z-direction -4.9

Test Article Deflections (mm)

Dynamic N/A
 Permanent 51

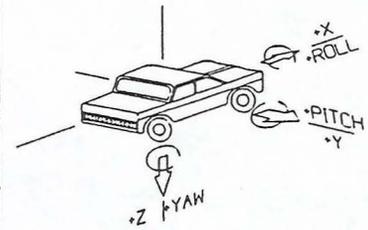
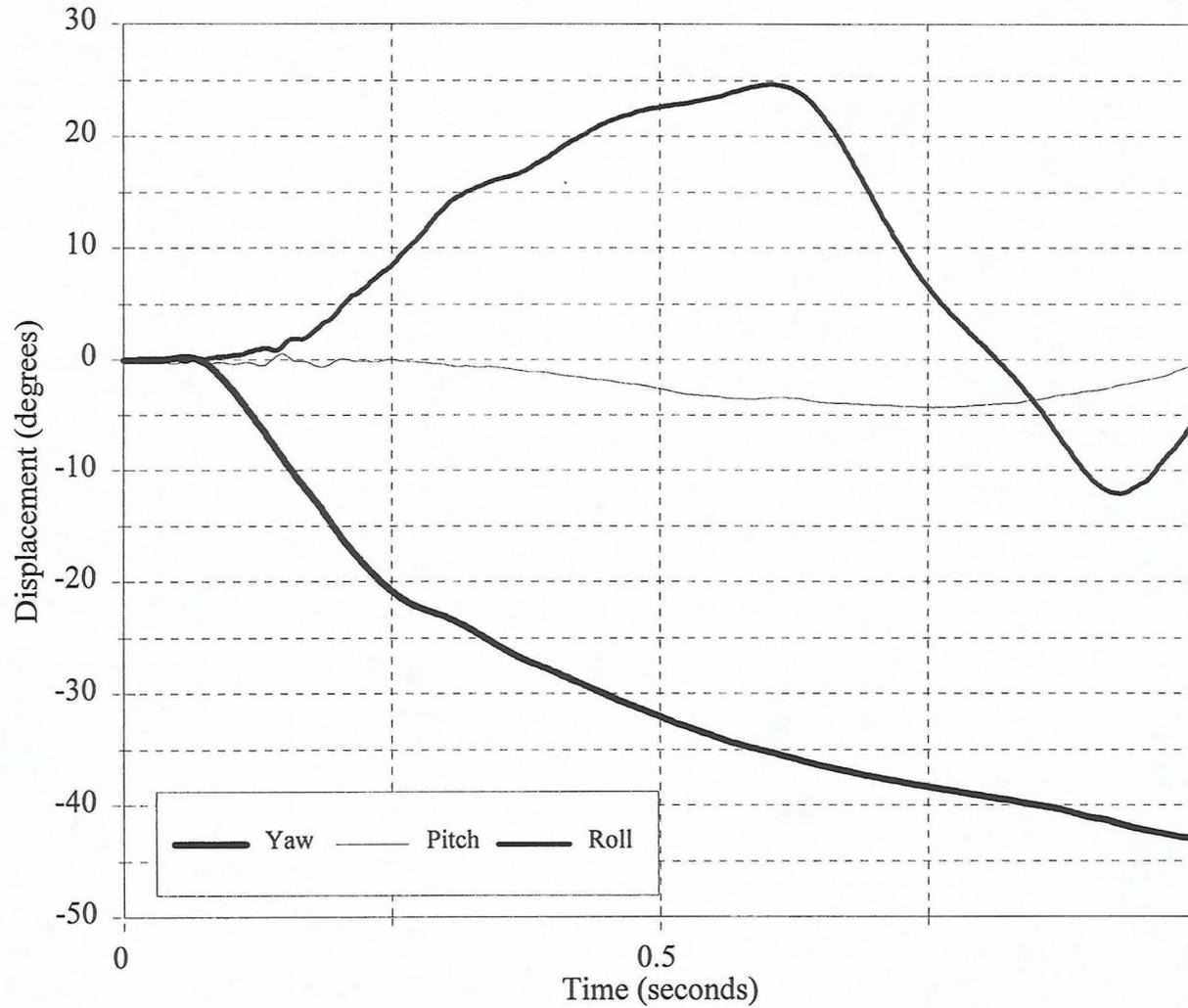
Vehicle Damage

Exterior
 VDS 01RFQ5
 CDC 01FREK4
 & 01RYES4
Interior
 OCDI FS0112000
Maximum Exterior
 Vehicle Crush (mm) 960
Max. Occ. Compartment
 Deformation (mm) 92
Post-Impact Behavior
 Max. Roll Angle (deg) -12
 Max. Pitch Angle (deg) -4
 Max. Yaw Angle (deg) -43

Figure 14. Summary of results for test 472610-4.

Crash Test 472610-4

Vehicle Mounted Rate Transducers



Axes are vehicle fixed.
Sequence for determining orientation is:

1. Yaw
2. Pitch
3. Roll

Figure 15. Vehicle angular displacements for test 472610-4.

Crash Test 472610-4

Rear accelerometer extrapolated to cg

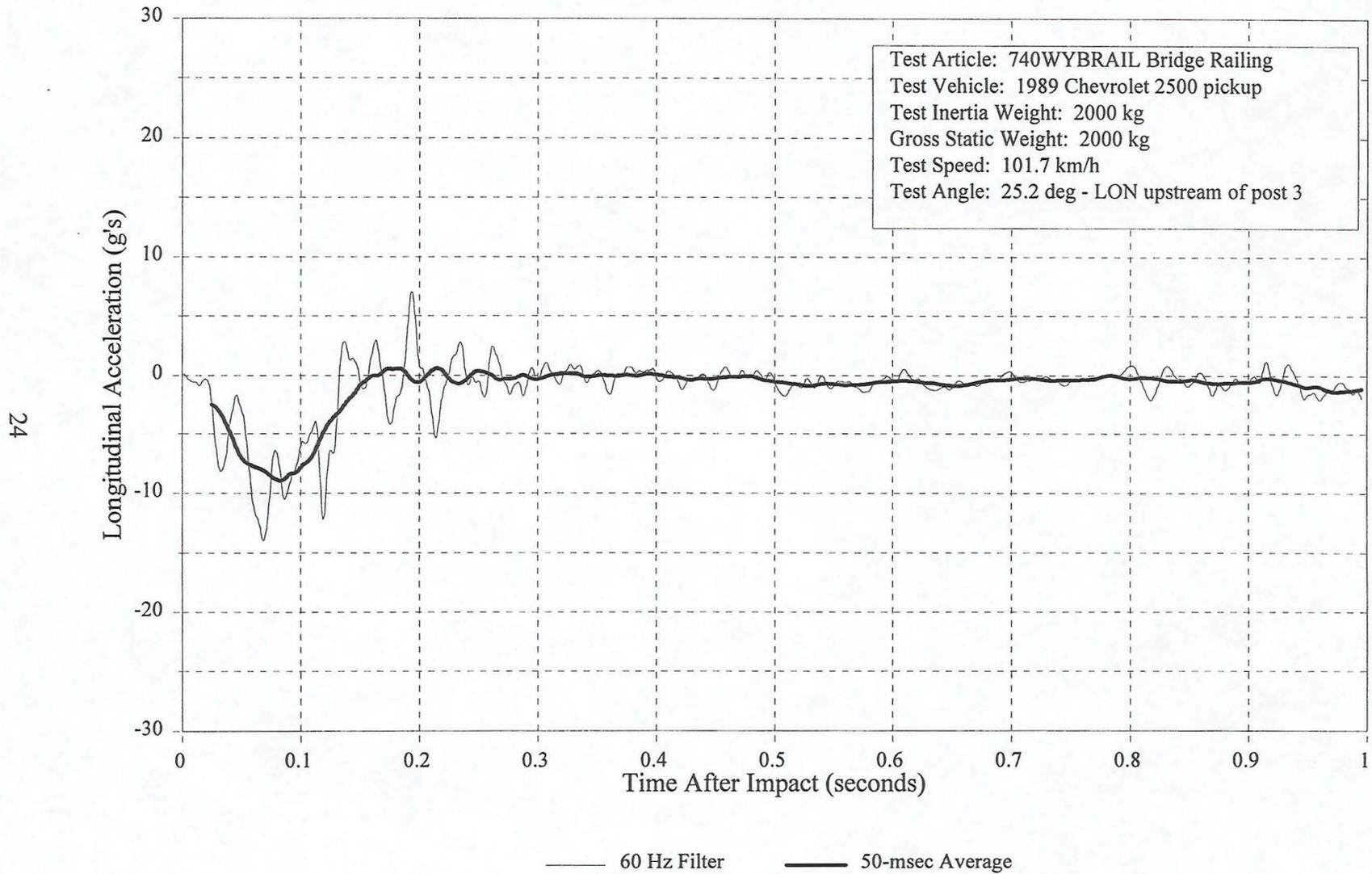


Figure 16. Vehicle longitudinal accelerometer trace for test 472610-4.

Crash Test 472610-4

Rear accelerometer extrapolated to cg

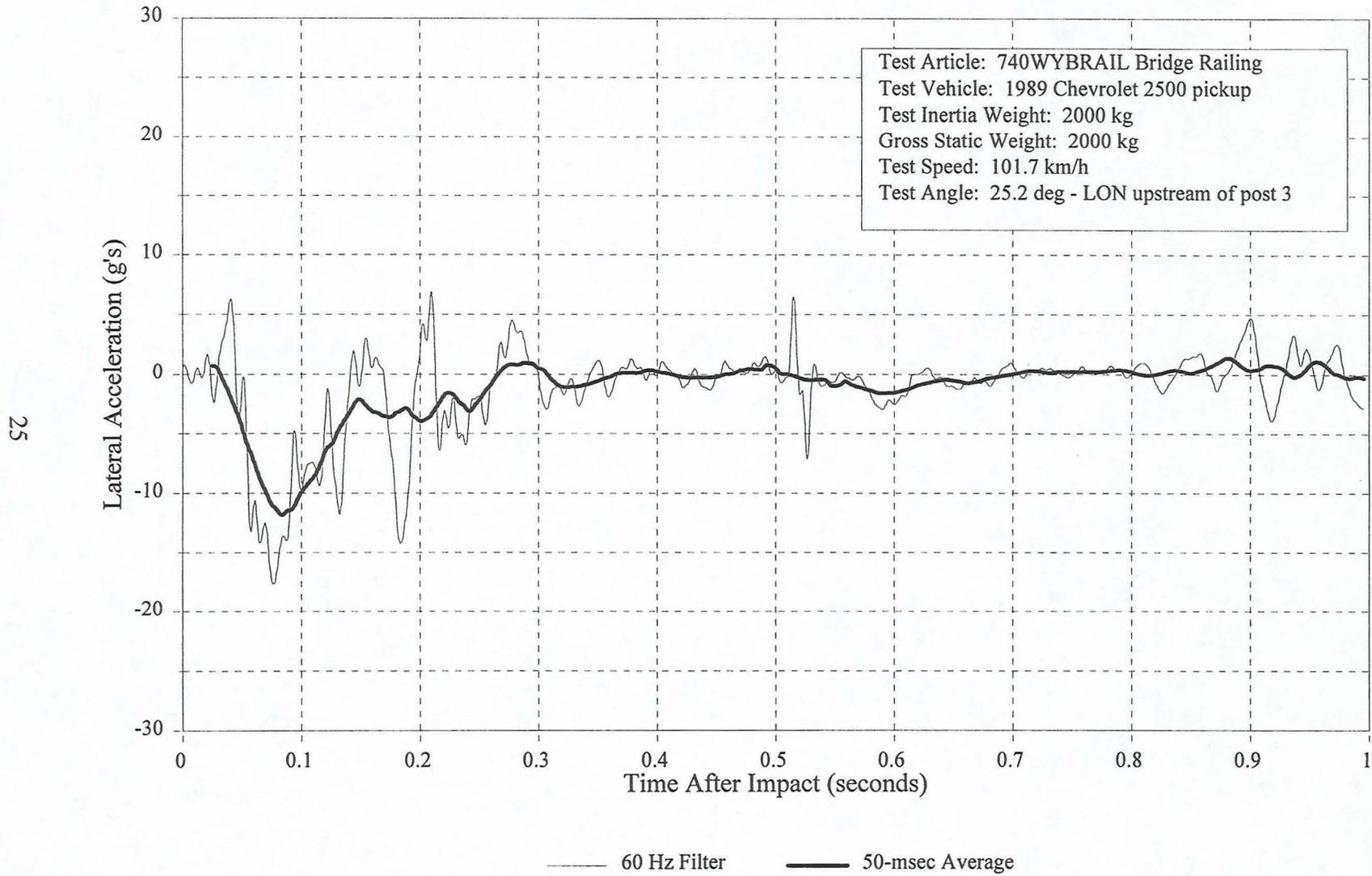


Figure 17. Vehicle lateral accelerometer trace for test 472610-4.

IV. SUMMARY OF FINDINGS AND CONCLUSIONS

4.1 SUMMARY OF FINDINGS

The existing Wyoming 740WYBRAIL bridge railing system contained and smoothly redirected the impacting vehicle. The vehicle did not penetrate or go over the bridge railing. There were no detached elements or debris to show potential for penetrating the occupant compartment or to present undue hazard to others in the area. Damage sustained by the vehicle was considered moderate given the severe nature of the impact conditions. Maximum deformation of the occupant compartment was 92 mm in the firewall area and was judged not to cause serious injury. The vehicle remained upright during and after the collision. The exit angle at loss of contact with the bridge railing was 9.2 degrees which was less than 60 percent of the test impact angle. Minimal, if any, intrusion into the adjacent traffic lanes was caused by the vehicle exit trajectory. The occupant risk factors were well within the preferred limits specified in NCHRP Report 350.

4.2 CONCLUSIONS

In summary, the existing Wyoming 740WYBRAIL bridge railing system was judged to have met all the evaluation criteria set forth in NCHRP Report 350 for test designation 3-11, as shown in table 1.

Table 1. Performance evaluation summary for test 472610-4, NCHRP Report 350 test 3-11.

Test Agency: Texas Transportation Institute		Test No.: 472610-4	Test Date: 02/12/96
NCHRP Report 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 740WYBRAIL bridge rail contained and redirected the vehicle. The vehicle did not penetrate or go over the bridge railing.	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 show potential for penetrating the occupant compartment or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 92 mm in the firewall area and was judged not to cause serious injury.	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.	Minimal, if any, intrusion into the adjacent traffic lanes was caused by the vehicle exit trajectory.	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 7.6 m/s and longitudinal occupant ridedown acceleration was 4.6 g.	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 with the bridge railing was 9.2 degrees which was less than 60 percent of the test impact angle.	Pass

REFERENCES

1. K. K. Mak and D. L. Bullard, "Testing and Evaluation of Wyoming Tube-Type Bridge Rail," Research Report 0368-1, Texas Transportation Institute, Texas A&M University System, College Station, Texas, March 1988.
2. J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, Washington, D.C., 1980.
3. H. E. Ross, Jr., D. L. Sicking, and R. A. Zimmer, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," NCHRP Report 350, Transportation Research Board, Washington, D.C., 1993.