Safety Performance Evaluation of the Foothills Parkway Bridge Rail

by

Brian G. Pfeifer
Research Associate Engineer

Ronald K. Faller
Research Associate Engineer

Midwest Roadside Safety Facility
Civil Engineering Department
University of Nebraska-Lincoln
1901 'Y' Street, Bldg. C
Lincoln, Nebraska 68588-0601

Sponsored by

Federal Highway Administration
Eastern Federal Lands Highway Division
21400 Ridgetop Circle
Sterling, Virginia 22170

submitted to

Charles F. McDevitt, P.E.
Contracting Officers Technical Representative

Transportation Research Report TRP-03-41-94

FHWA Contract No. DTFH71-90-C-00035

January 1994

ACKNOWLEDGEMENTS

The authors wish to express their appreciation and thanks to the Federal Highway Administration for funding the research described herein and the Center for Infrastructure Research for purchasing equipment used in the testing. A special thanks is also given to the following individuals who made a contribution to this research project.

Midwest Roadside Safety Facility

Jim Holloway, Research Associate Engineer

Federal Highway Administration

Charles McDevitt, Project Manager and Research Structural Engineer

Center for Infrastructure Research

Maher Tadros, Ph.D., Director
Samy Elias, Ph.D., Associate Dean for Engineering Research Center

Midwest Transportation Center

Tom Maze, Director

Arizona Department of Transportation

Richard Bruesch, Bridge Operations Engineer
C. Dennis Grigg, Assistant State Engineer - Structures

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

1. INTRODUCTION

1.1 Background

The Coordinated Federal Lands Highways Technology Improvement Program (CTIP) was developed with the purpose of serving the immediate needs of those who design and construct Federal Lands Highways, including Indian Reservation roads, National Park roads and parkways, and forest highways. A wide assortment of guardrails, bridge rails and transitions are being used on roads under the jurisdiction of the National Park Service and other Federal agencies. These guardrails, bridge rails and transitions are intended to blend in with the roadside in order to preserve the visual integrity of the parks and parkways. However, many of them have never been crash tested (1,2). A testing program was developed in order to ensure that the safety hardware used in these areas are safe for the traveling public. The Foothills Parkway Aluminum Bridge Rail was included in the second Federal Highway Administration (FHWA) testing program - Guardrail Testing Program II.

1.2 Test Installation

Photographs of the Foothills Parkway Bridge Rail are shown in Figures 1 and 2. This system consists of cast aluminum posts mounted on a 6 in. (15.2 cm) curb, supporting two aluminum rails. Throughout the course of the safety evaluation of this system, the design was changed twice. The original design, shown in Figure 3, was evaluated during Test FPAR-1. The system was modified for Test FPAR-2 by adding longitudinal steel to the curb as shown in Figure 4. The final design evaluated in Test FPAR-3 is shown in Figure 5. The reasons for these design changes are discussed in the *Test Results* section.

The 75 ft (22.9 m) long bridge rail was constructed with a simulated bridge deck in order to test the adequacy of the post-to-deck connection, in addition to the rail itself. A cross-section of the 80 ft (24.4 m) long simulated bridge deck is shown in Figure 6. Grade 60 epoxy coated reinforcement was used in the deck.

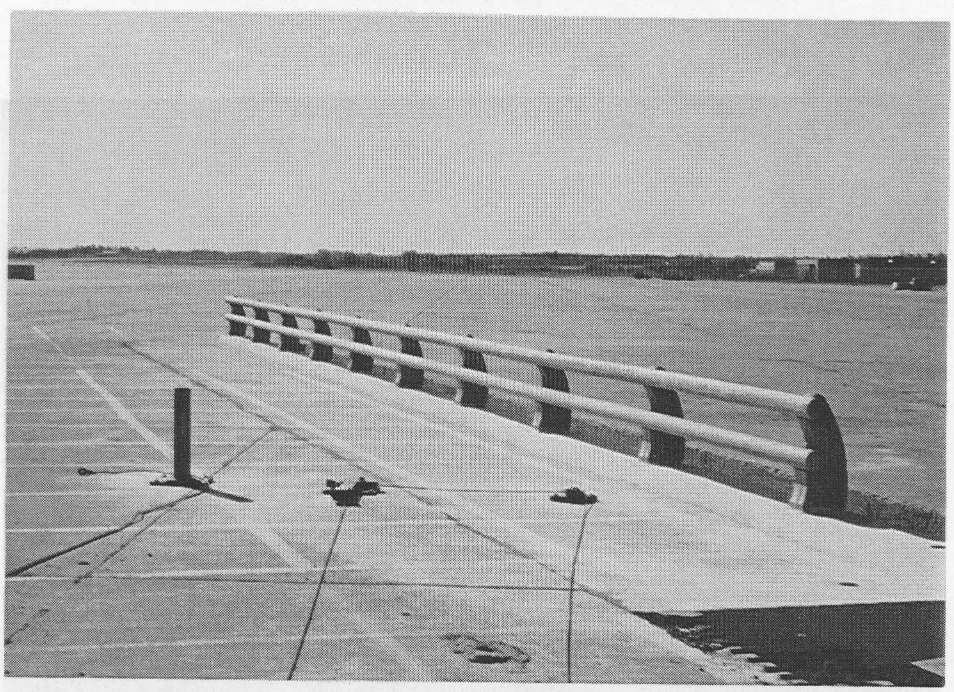
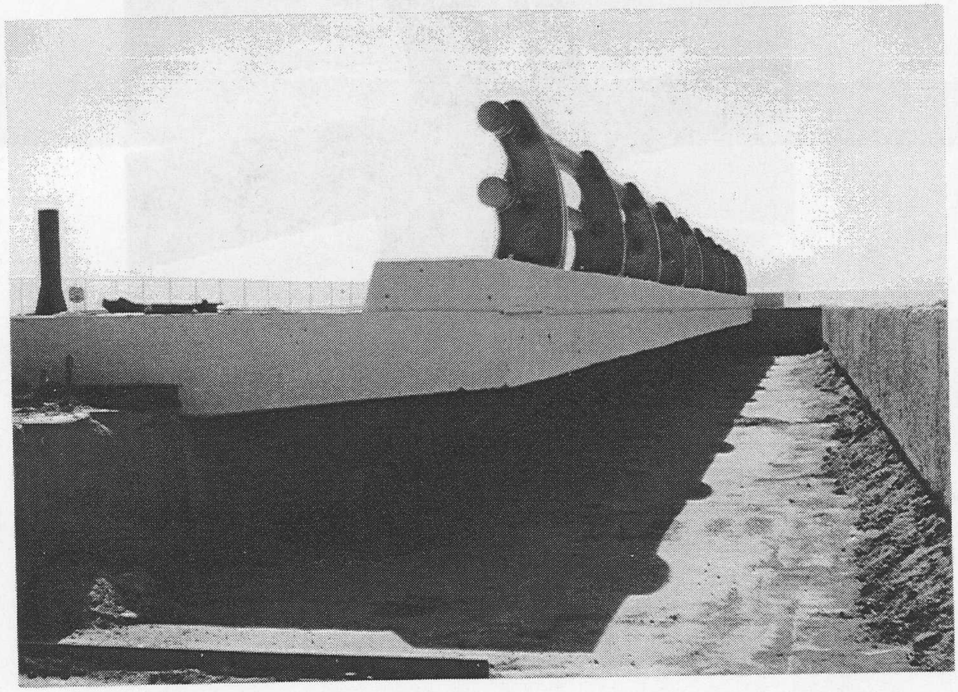


Figure 1. The Foothills Parkway Bridge Rail



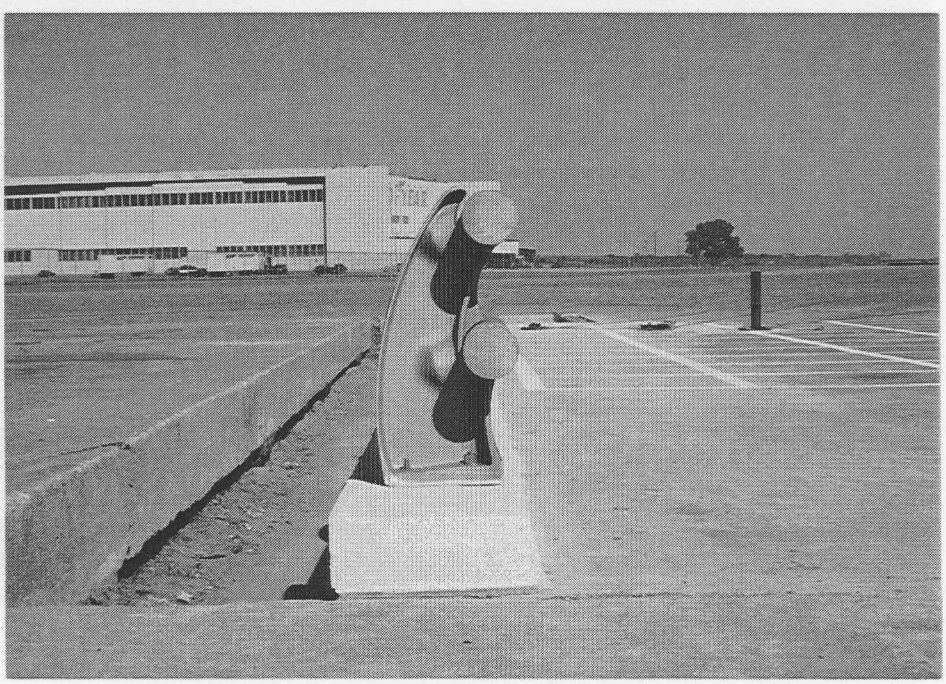


Figure 2. The Foothills Parkway Bridge Rail (cont.)

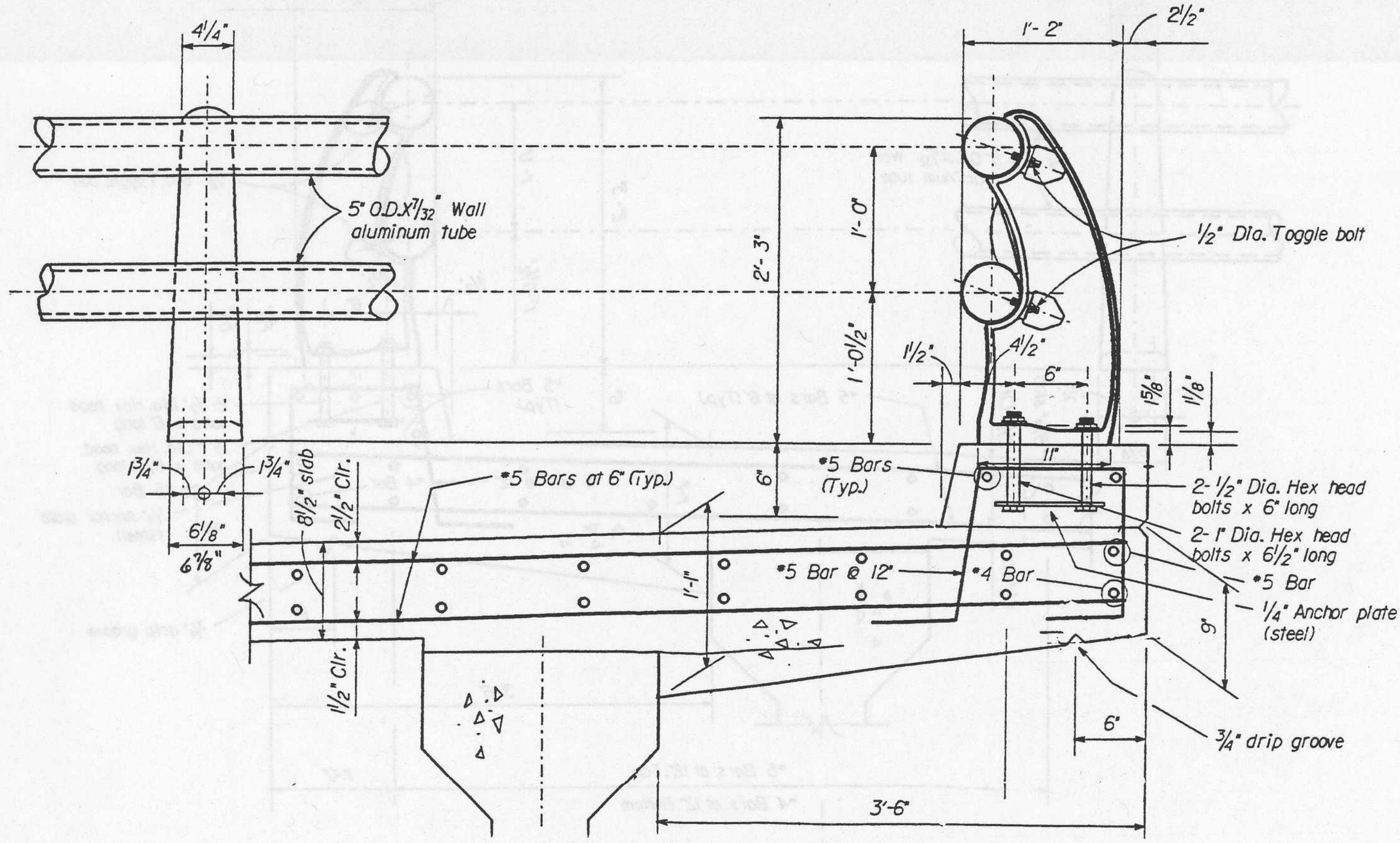


Figure 3. Design Details of the Foothills Parkway Bridge Rail for Test FPAR-1

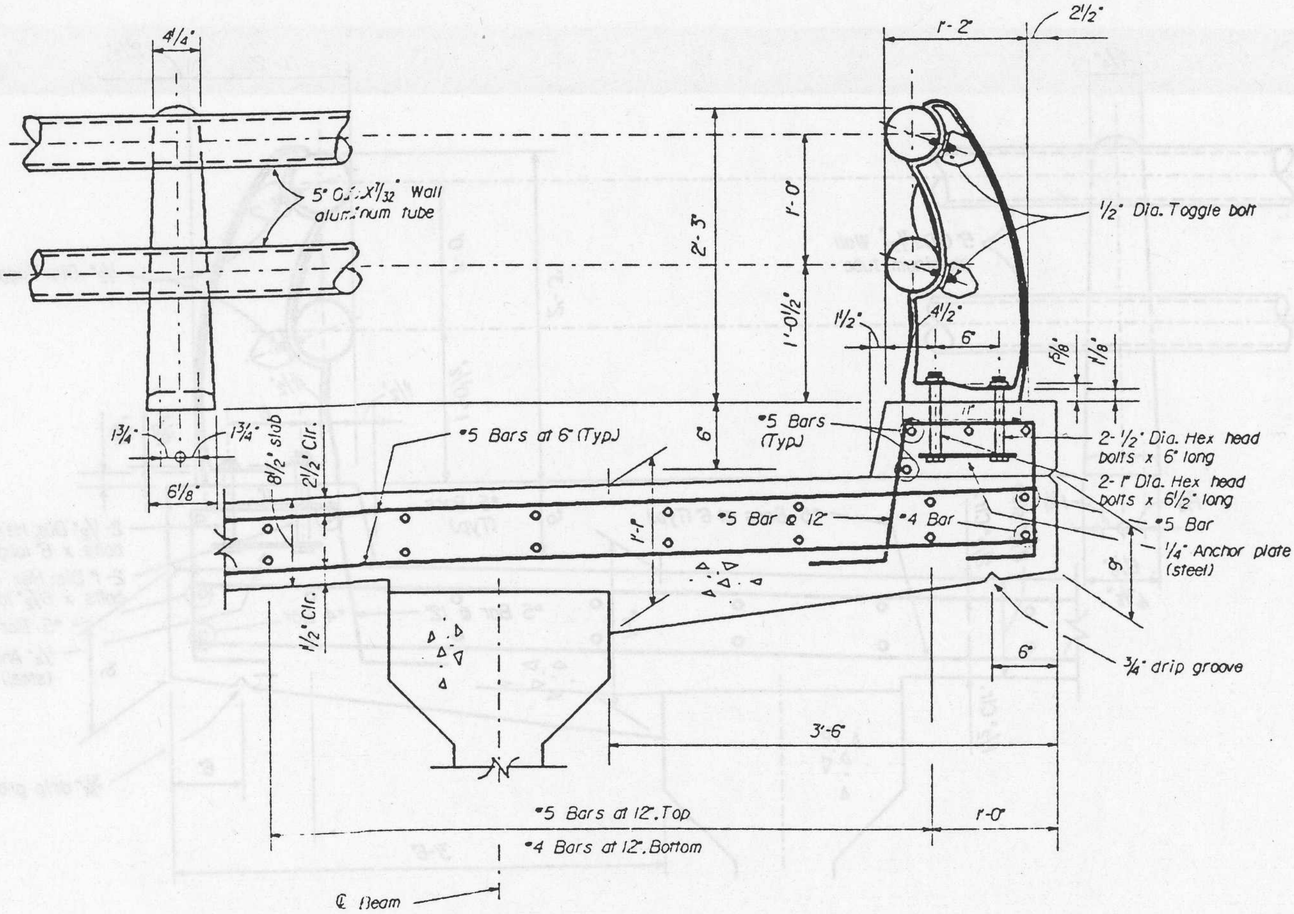


Figure 4. Design Details of the Foothills Parkway Bridge Rail for Test FPAR-2

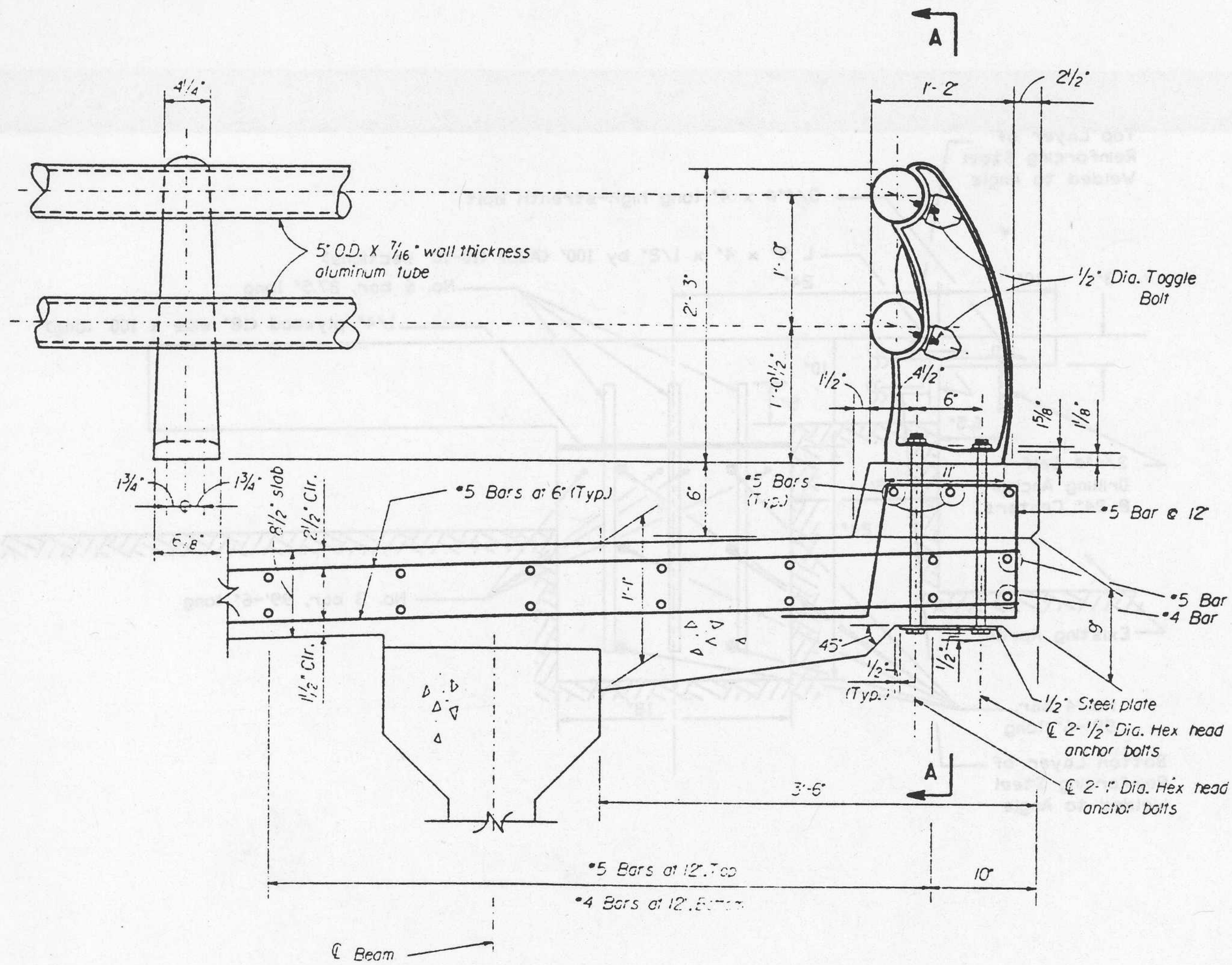


Figure 5. Design Details of the Foothills Parkway Bridge Rail for Test FPAR-3

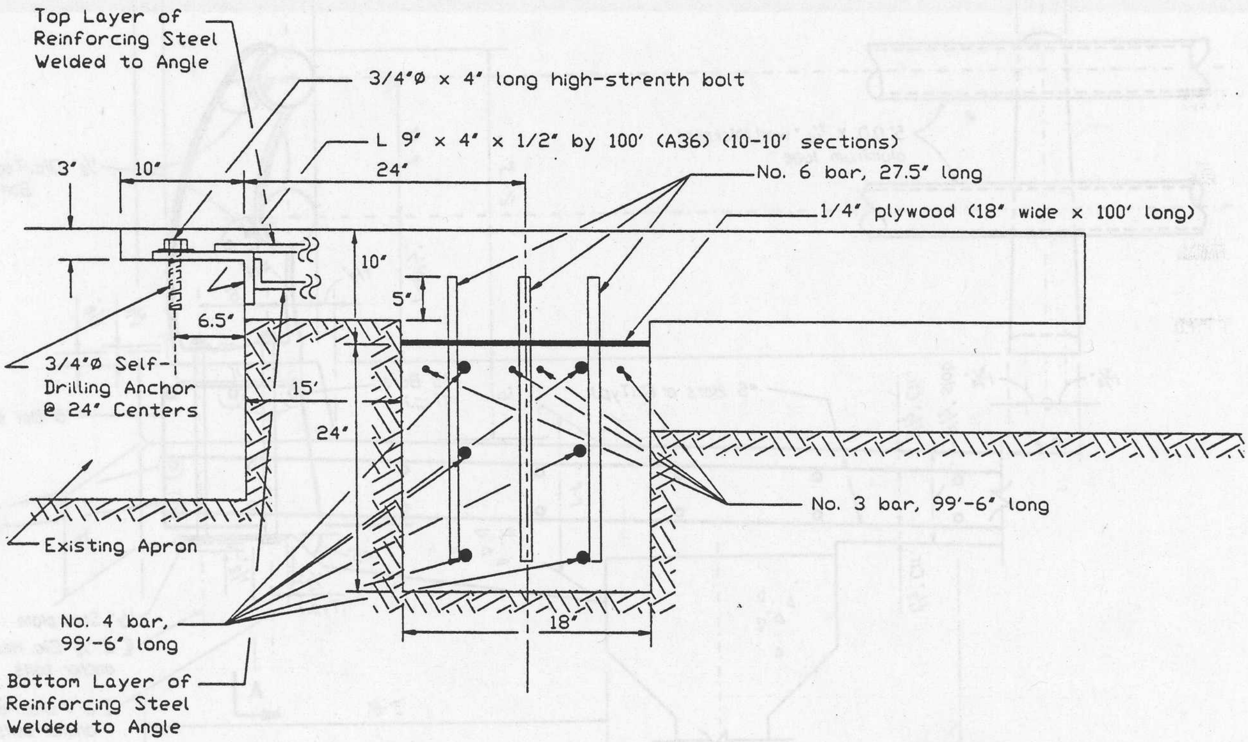


Figure 6. Cross-section of the simulated concrete deck

2. TEST CONDITIONS

2.1 Test Vehicles

A 1984 Dodge Colt, shown in Figure 7, was used as a test vehicle in Test FPAR-1. As shown in Figure 8, the vehicle had a test inertial weight of 1,904 lbs (864 kg).

A 1984 Chevrolet 3/4-ton pickup, shown in Figure 9, was used as a test vehicle in Test FPAR-2. As shown in Figure 10, the vehicle had a test inertial weight of 5,300 lbs (2,300 kg).

A 1985 Ford 3/4-ton pickup, shown in Figure 11, was used as a test vehicle in Test FPAR-3. As shown in Figure 12, the vehicle had a test inertial weight of 5,400 lbs (2,452 kg).

Black and white-checkered targets were placed on the test vehicle for high-speed film analysis. Two targets were located on the center of gravity, one on the top and one on the driver's side of the test vehicle. Additional targets, visible from all three external high speed cameras, were located for reference. The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs, fired by a pressure tape switch on the front bumper, were mounted on the roof of each vehicle to establish the time of impact on the high-speed film.

Figure 7. Test Vehicle, Test FPAR-1

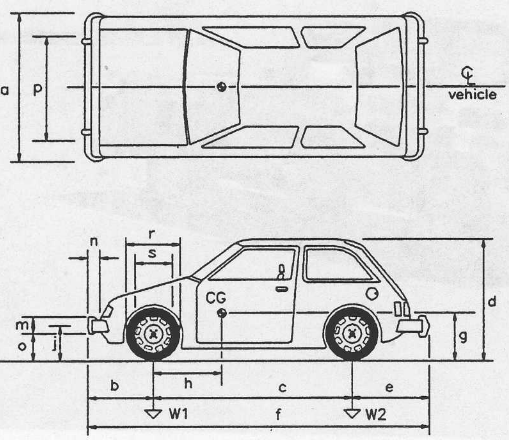
Make: Dodge — Test No.: FPAR-1

Model: Colt — Tire Size: P155/80R13

Year: 1984

Vehicle Geometry
Inches

a —	60.0	b —	34.5
c —	90.0	d —	52.0
e —	32.0	f —	156.5
g —	21.0	h —	34.9
j —	17.5	m —	4.5
n —	6.5	o —	15.25
p —	51.5	r —	22.5
s —	15		



Engine Size: 4 cyl.

Transmission: manual

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	735	1166	1265
W2	1095	738	804
Wtotal	1850	1904	2069

Damage prior to test: NONE

Conversion Factors: 1in.=2.54cm. 1lb.=0.454kg.

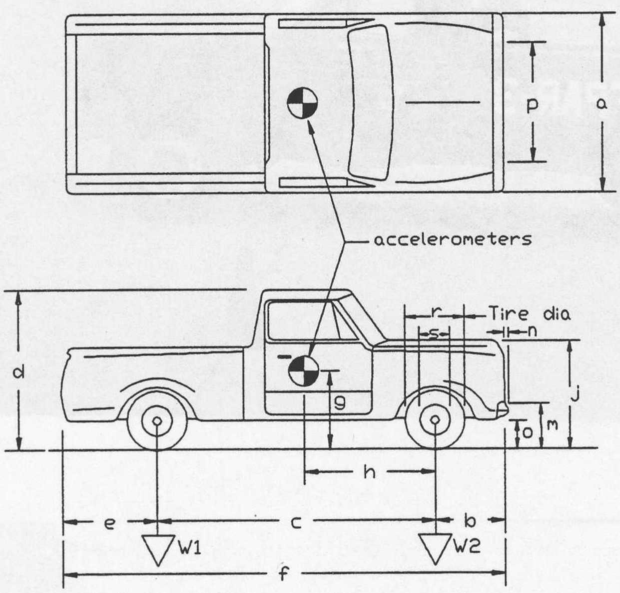
Figure 8. Test Vehicle Dimensions, Test FPAR-1

Figure 9. Test Vehicle, Test FPAR-2

Date: 3/13/92 | Test No.: FPAR-2 | Vehicle I.D. #: 1GCGC24MXE1171709

Make: Chevrolet | Model: 3/4 ton Custom Deluxe C-20

Tire Size: LT235/85R16 | Year: 1984 | Odometer: 106270



Vehicle Geometry - inches

a	79	b	33
c	132	d	71.5
e	53.5	f	218.5
g	26	h	69
i	—	j	44.5
k	—	l	—
m	26	n	4
o	17	p	66
r	31.5	s	17.5

Engine Type: 8cyl.

Engine Size: 350cu./in.

4 - wheel weight: lf____ rf____ lr____ rr____

Transmission Type:

Automatic or (Manual)

FWD or (RWD) or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1990	2770	2843
W2	2530	2530	2622
Wtotal	4520	5300	5465

Note any damage prior to test: none

Conversion Factors: 1in.=2.54cm. 1lb.=0.454kg.

Figure 10. Test Vehicle Dimensions, Test FPAR-2

Figure 11. Test Vehicle, Test FPAR-3

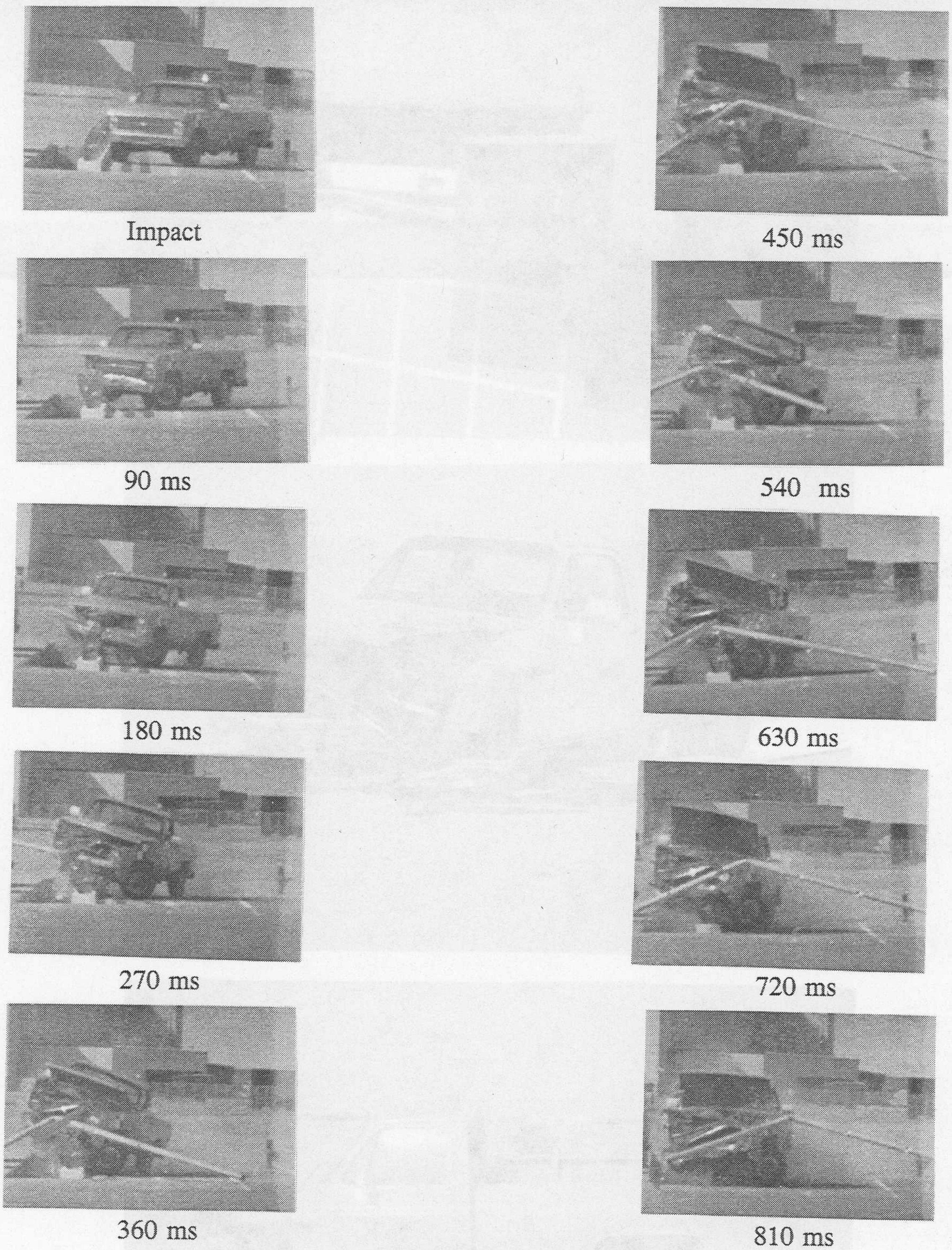


Figure 24. Downstream Sequential Photographs, Test FPAR-2

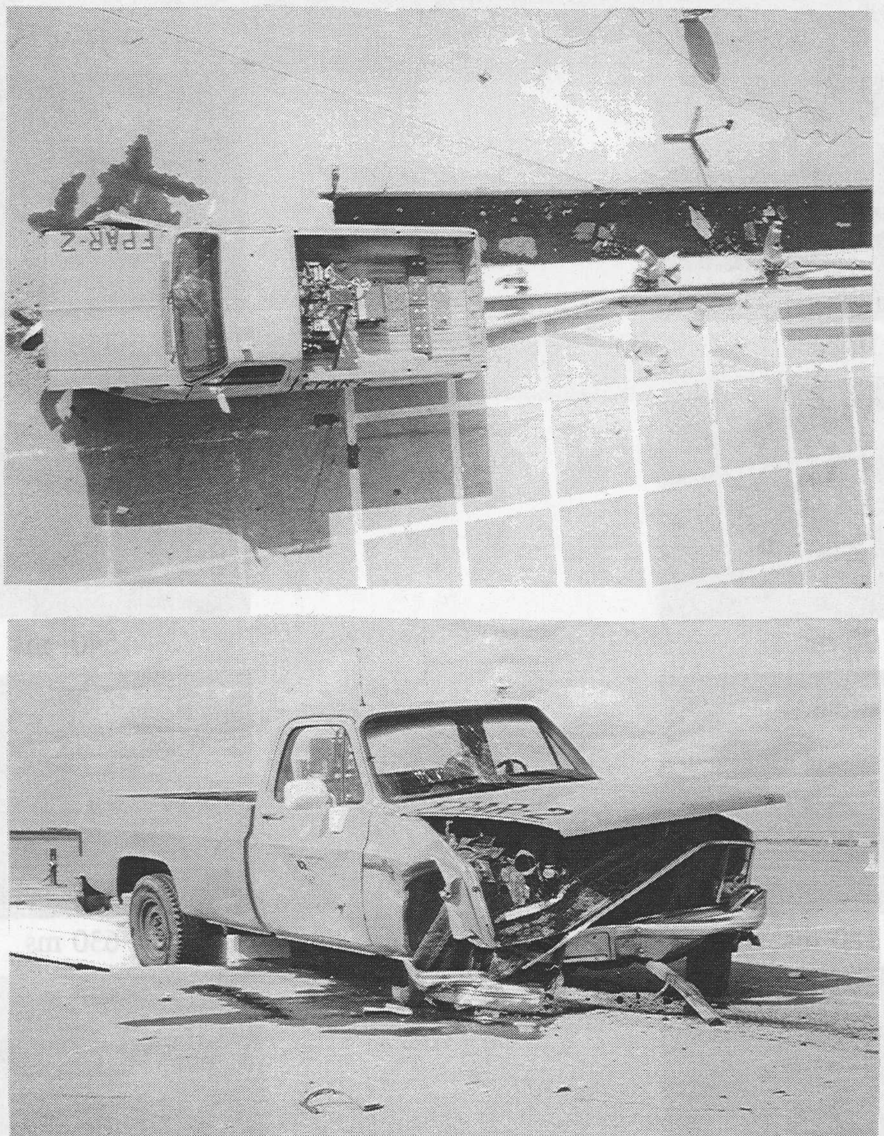


Figure 25. Vehicle Damage, Test FPAR-2

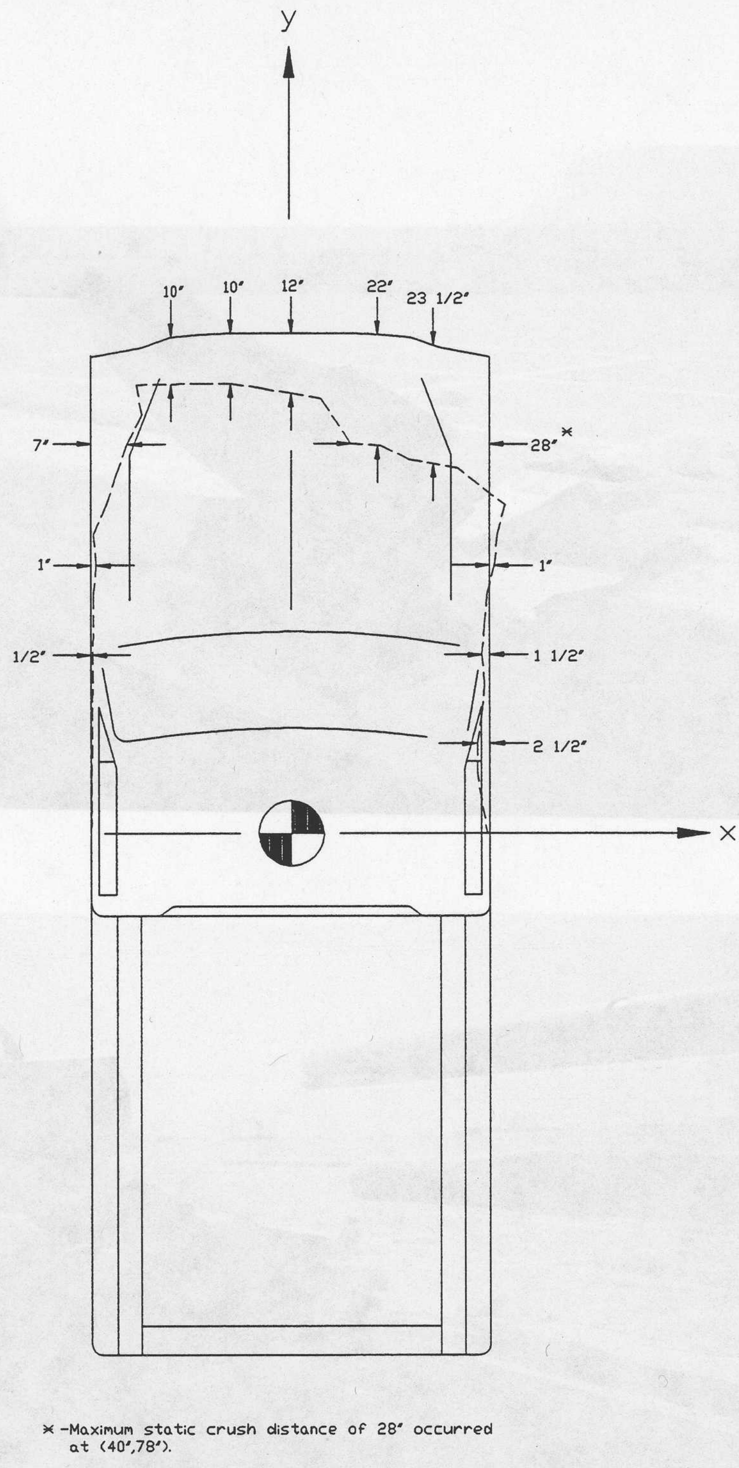


Figure 26. Crush depth diagram, Test FPAR-2

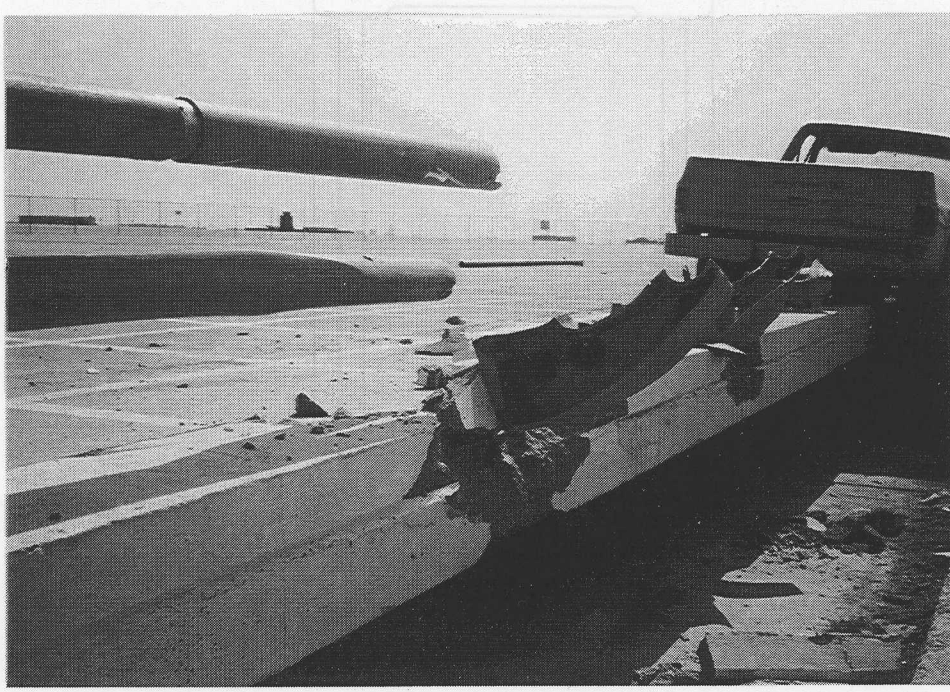


Figure 27. Bridge Rail Damage, Test FPAR-2

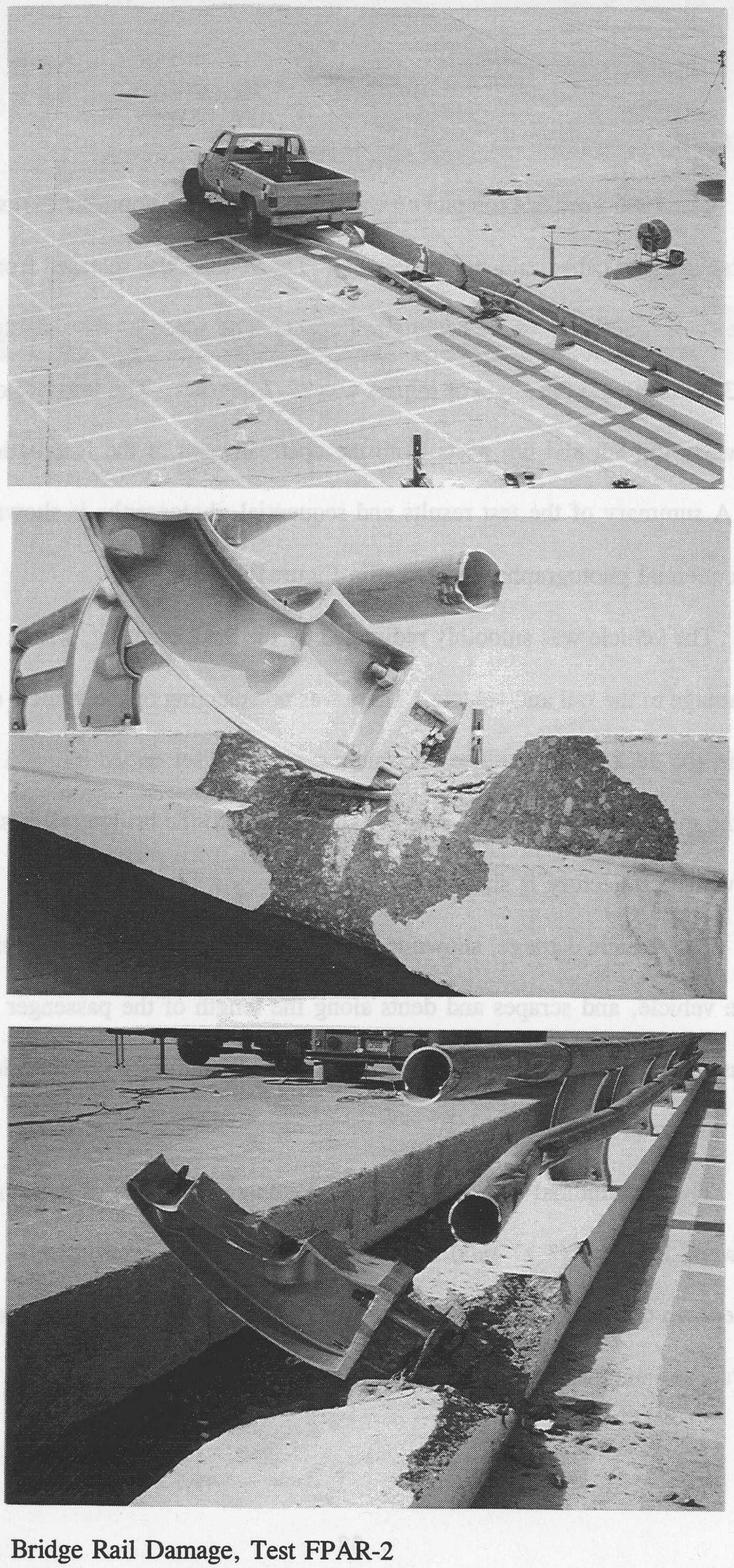


Figure 28. Bridge Rail Damage, Test FPAR-2

3.3 Test FPAR-3

The 1985 Ford 3/4 ton pickup was directed into the Foothills Parkway Bridge Rail using a reverse tow and cable guidance system (3). The vehicle was released from the tow cable and guidance system and was free wheeling at impact. The speed of the vehicle at impact was 45.7 mph (73.5 km/h) and the angle of impact was 22.7 degrees. The impact point was located midspan between the 5th and 6th posts from the upstream end of the installation as shown in Figure 29. A summary of the test results and sequential photographs is shown in Figure 30. Additional sequential photographs are shown in Figure 31.

The vehicle was smoothly redirected by the bridge railing, with a relatively small amount of damage to the rail and vehicle. There was no snagging of the vehicle or any evidence of cracking in the deck or curb. The maximum permanent set deflection of 1.9 in. (4.8 cm) occurred at the midspan of post Nos 5 and 6. The damage to the bridge rail is shown in Figure 32, and the vehicle trajectory is shown in Figure 33.

The vehicle damage, shown in Figure 34, included the crushing of the right front corner of the vehicle, and scrapes and dents along the length of the passenger side. The right front tire was blown out and the rim was bent. The maximum crush deformation of 10.75 in. (27.3 cm) is shown in Figure 35.

The longitudinal and lateral occupant impact velocities as determined from high speed film were 10.4 fps (3.17 m/s) and 16.0 fps (4.88 m/s), respectively. The maximum occupant ridedown decelerations were 6.0 g's (longitudinal), and 8.0 g's (lateral). The results of this analysis are summarized in Figure 30 and Table 2.

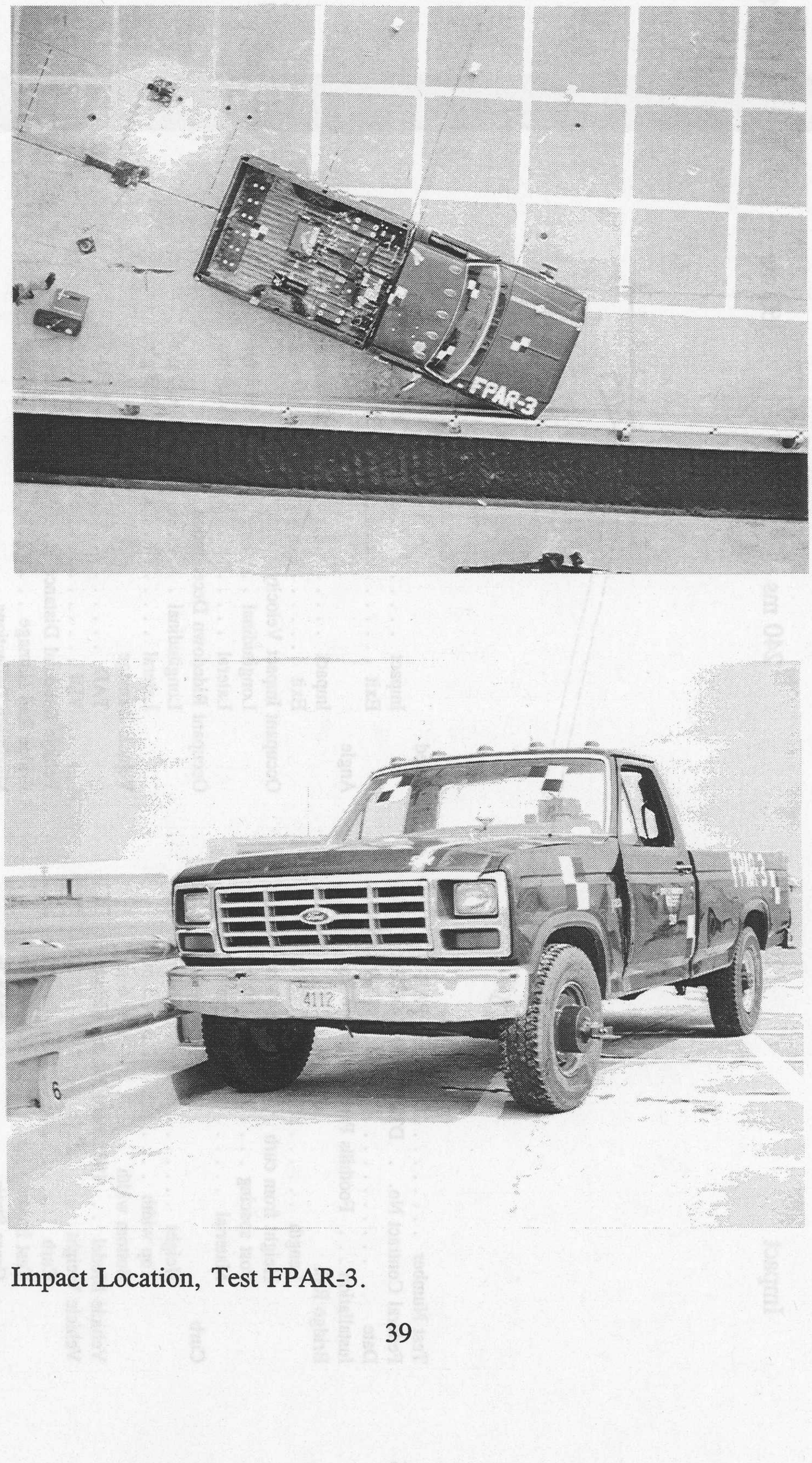
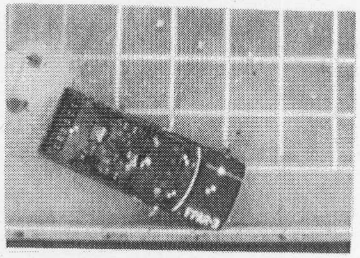
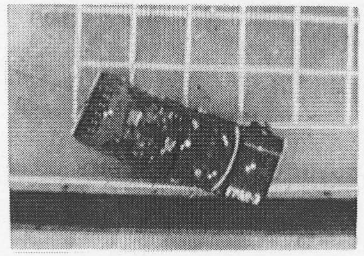


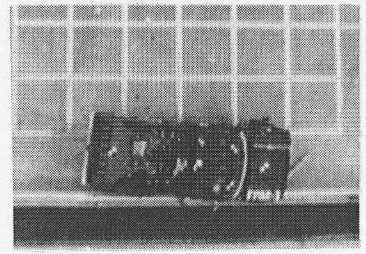
Figure 29. Impact Location, Test FPAR-3.



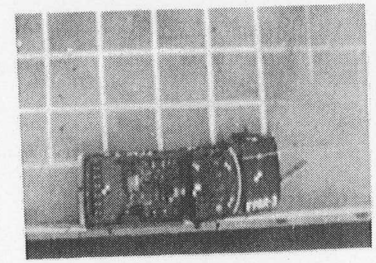
Impact



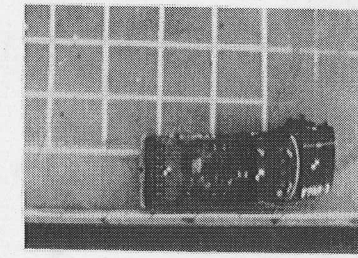
120 ms



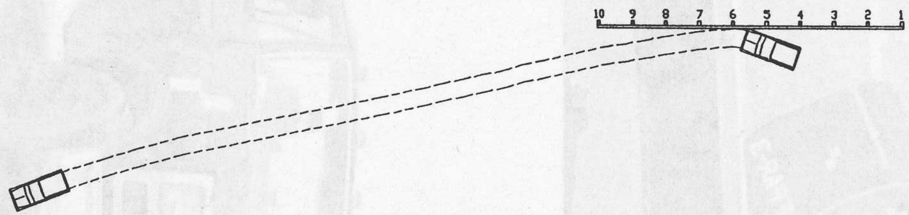
240 ms



360 ms



480 ms



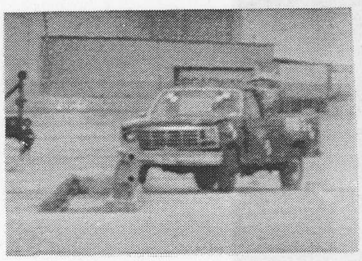
Test Number	FPAR-3
Federal Contract No.	DTFH71-90-C-00035
Date	6-7-93
Installation	Foothills Parkway Bridge Rail
Bridge Rail	
Length	75 ft
Height from curb	2 ft- 3 in.
Post spacing	7 ft- 10 in.
Material	Aluminum
Curb	
Height	6 in.
Top width	1 ft- 4.5 in.
Bottom width	1 ft- 6 in.
Vehicle Model	1985 Ford 3/4 ton pickup
Vehicle Weight	
Curb	4060 lb
Test Inertia	5400 lb
Gross Static	5565 lb

Speed	
Impact	45.7 mph
Exit	30.6 mph
Angle	
Impact	22.7 deg
Exit	5.0 deg
Occupant Impact Velocity	
Longitudinal	10.4 fps
Lateral	16.0 fps
Occupant Ridedown Deceleration	
Longitudinal	6.0 g's
Lateral	8.0 g's
Vehicle Damage	
TAD	1-RFQ-3
VDI	01RYES2
Vehicle Rebound Distance	24 ft
Bridge Rail Damage	Minor
Maximum Deflections	
Permanent Set	1.9 in.
Dynamic	NA

Conversion Factors: 1 in. = 2.54 cm; 1 lb = .454 kg

Figure 30. Summary of Test FPAR-3

Impact



60 ms

120 ms

180 ms

240 ms

300 ms

360 ms

420 ms

Figure 31. Downstream Sequential Photographs, Test FPAR-3

Figure 32. Bridge Rail Damage, Test FPAR-3

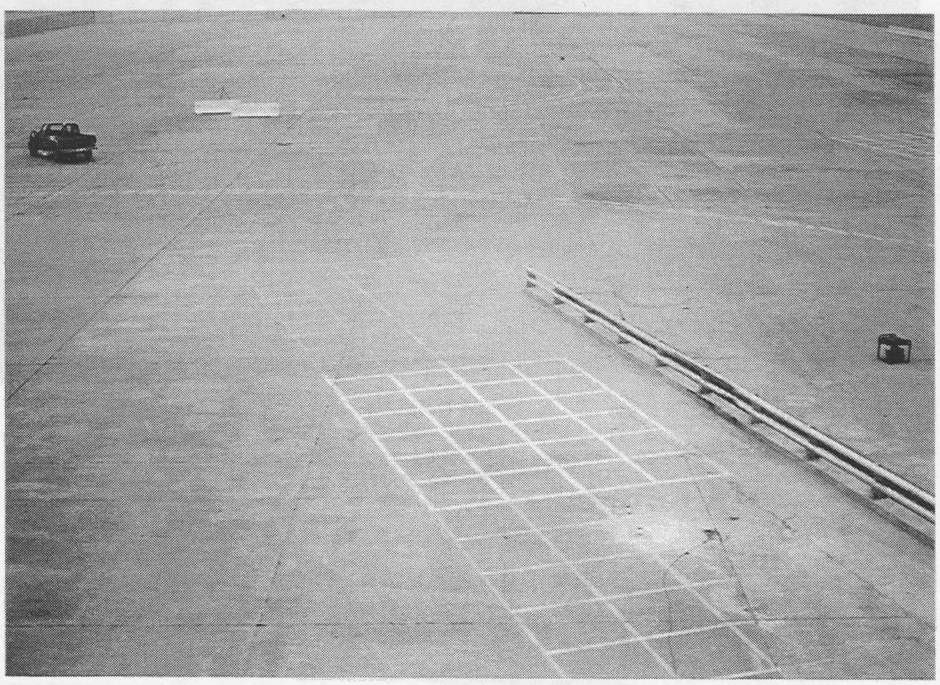


Figure 33. Vehicle Trajectory, Test FPAR-3

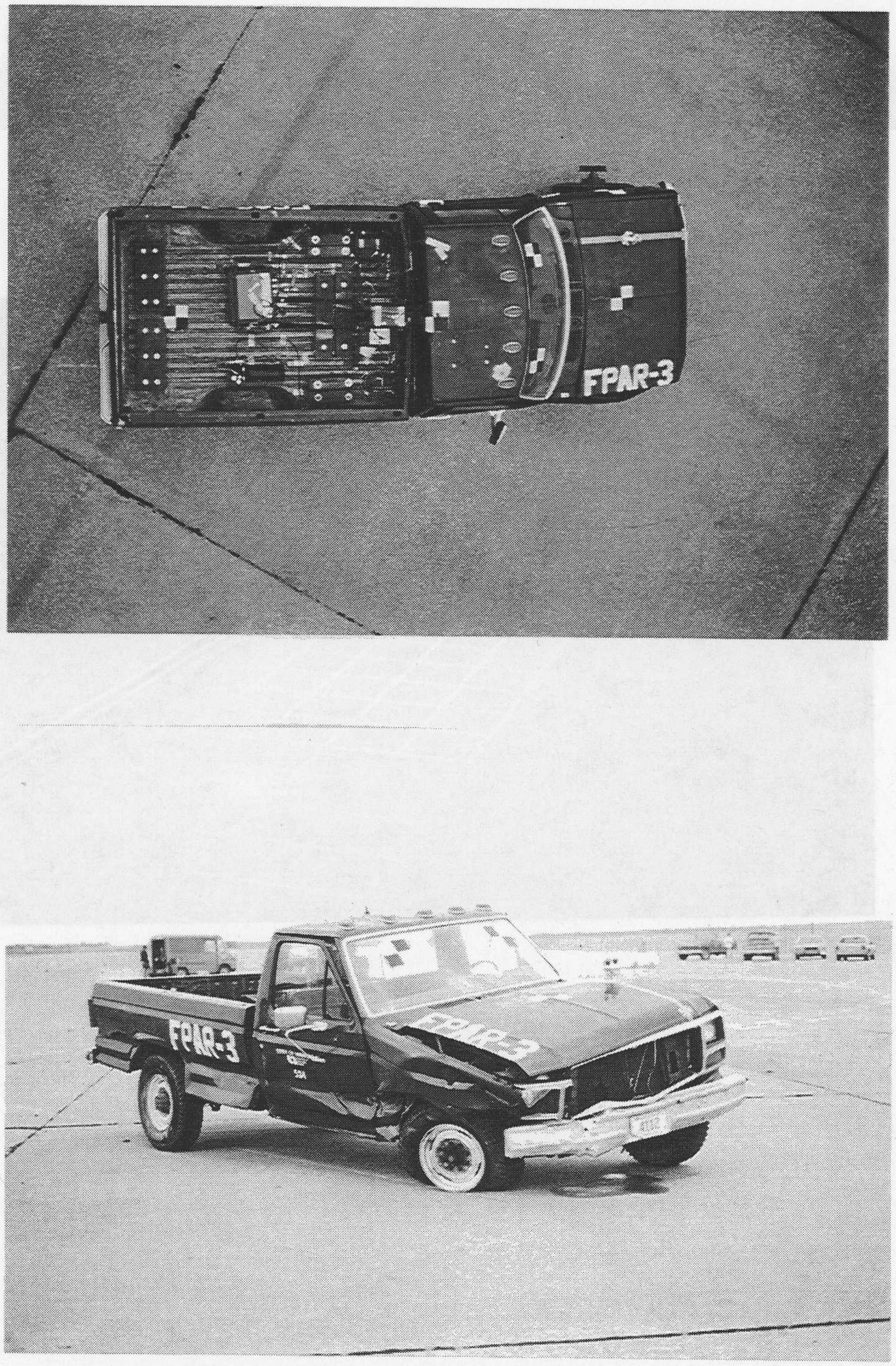
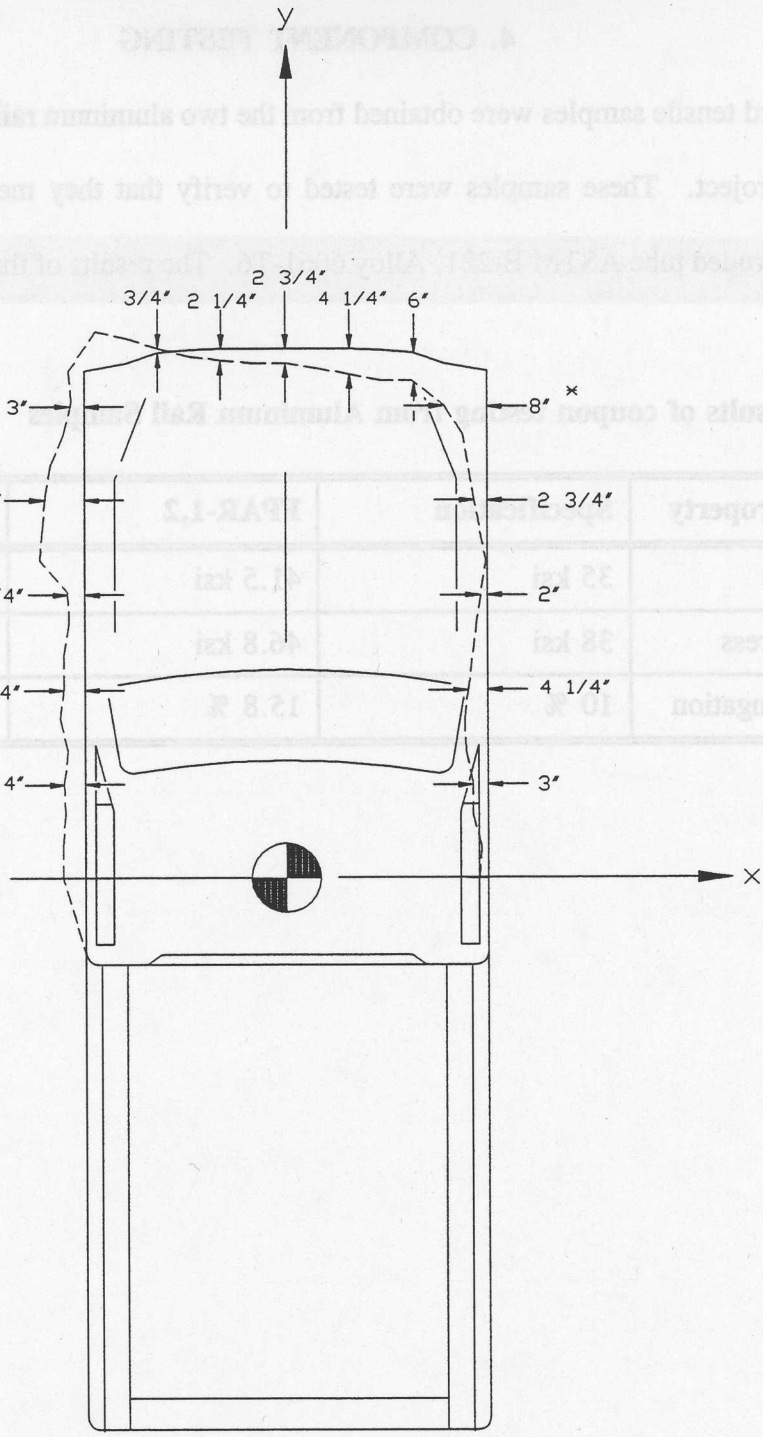


Figure 34. Vehicle Damage, Test FPAR-3



×-Maximum static crush distance of 8″ occurred at (30″,89 1/4″)

Conversion factor: 1in.=2.54cm.

Figure 35. Crush Depth Diagram, Test FPAR-3

4. COMPONENT TESTING

Standard tensile samples were obtained from the two aluminum rails which were evaluated during this project. These samples were tested to verify that they met the specifications for aluminum extruded tube ASTM B-221, Alloy 6061-T6. The results of this testing is summarized in Table 1.

Table 1. Results of coupon testing from Aluminum Rail Samples

Material Property	Specification	FPAR-1,2	FPAR-3
Yield Stress	35 ksi	41.5 ksi	43.8 ksi
Ultimate Stress	38 ksi	46.8 ksi	45.3 ksi
Percent Elongation	10 %	15.8 %	9.9 %

5. CONCLUSIONS

The tests described herein were evaluated according to criteria for performance level 1 bridge rails presented in AASHTO Guide Specifications for Bridge Rails (4). They were conducted and reported in accordance with the requirements in NCHRP Report 230 (5). Table 2 summarizes all of the relevant evaluation criteria from AASHTO (4), as well as the findings from the three tests reported herein. As shown in this table, the Foothills Parkway Bridge Rail successfully passed all requirements for performance level 1 bridge rails.

Table 2. Summary of Safety Performance Results

Evaluation Criteria	Results		
	FPAR-1	FPAR-2	FPAR-3
3.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.	S	U	S
3.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.	S	U	S
3.c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	S	S	S
3.d. The vehicle shall remain upright during and after collision.	S	S	S
3.e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.	S	U	S
3.f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_p/V)/\sin\theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair > 0.35 — Marginal	F (μ = 0.28)	NA	F (μ = 0.34)
3.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 30, Lateral 25	Occupant Impact Velocity (fps) Long.: S (9.6) Lat.: S (23.0)	Long.: S (10.4) Lat.: S (16.0)	Long.: S (10.4) Lat.: S (16.0)
and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than: Occupant ridedown Accelerations - g's Longitudinal 15, Lateral 15	Occupant Ridedown Accelerations (g's) Long.: S (5.7) Lat.: S (4.3)	Long.: S (6.0) Lat.: S (8.0)	Long.: S (6.0) Lat.: S (8.0)
3.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.	S (5.4 deg) U (37 ft @ 113 ft)	NA NA	S (5.0 deg) U (24.0 ft @118 ft)

S = Satisfactory
M = Marginal
U = Unsatisfactory

Conversion Factor: 1 ft = 0.3048 m

6. REFERENCES

1. Hancock, K.L., Hansen, A.G., Mayer, J.B., *Aesthetic Bridge Rails, Transitions, and Terminals for Park Roads and Parkways*, Federal Highway Administration, Report No. FHWA-RD-90-052, May 1990.

2. Stout, D., Hinch, J., Sawyer, D., *Guardrail Testing Program*, Federal Highway Administration, Report No. FHWA-RD-90-087, June 1990.

3. Hinch, J., Yang, T-L, and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, VA, 1986.

4. *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials, Washington, D.C., 1989.

5. *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report No. 230, Transportation Research Board, Washington, D.C., March 1981.

7. APPENDICES

APPENDIX A.

ACCELEROMETER DATA ANALYSIS, TEST FPAR-2

Figure A-1 Graph of Longitudinal Deceleration

Figure A-2 Graph of Longitudinal Occupant Impact Velocity

Figure A-3 Graph of Lateral Deceleration

Figure A-4 Graph of Lateral Occupant Impact Velocity

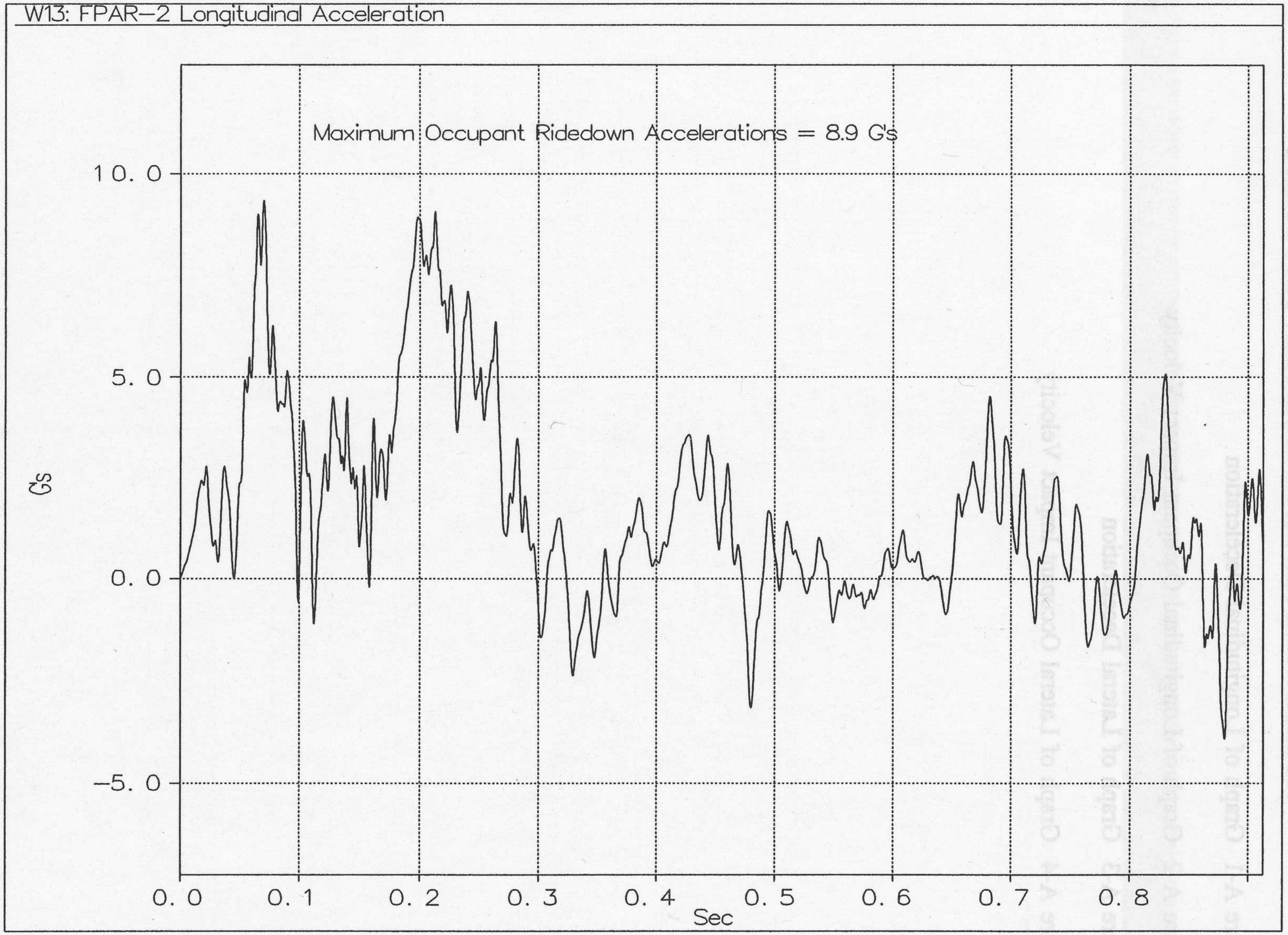


Figure A-1. Graph of Longitudinal Deceleration

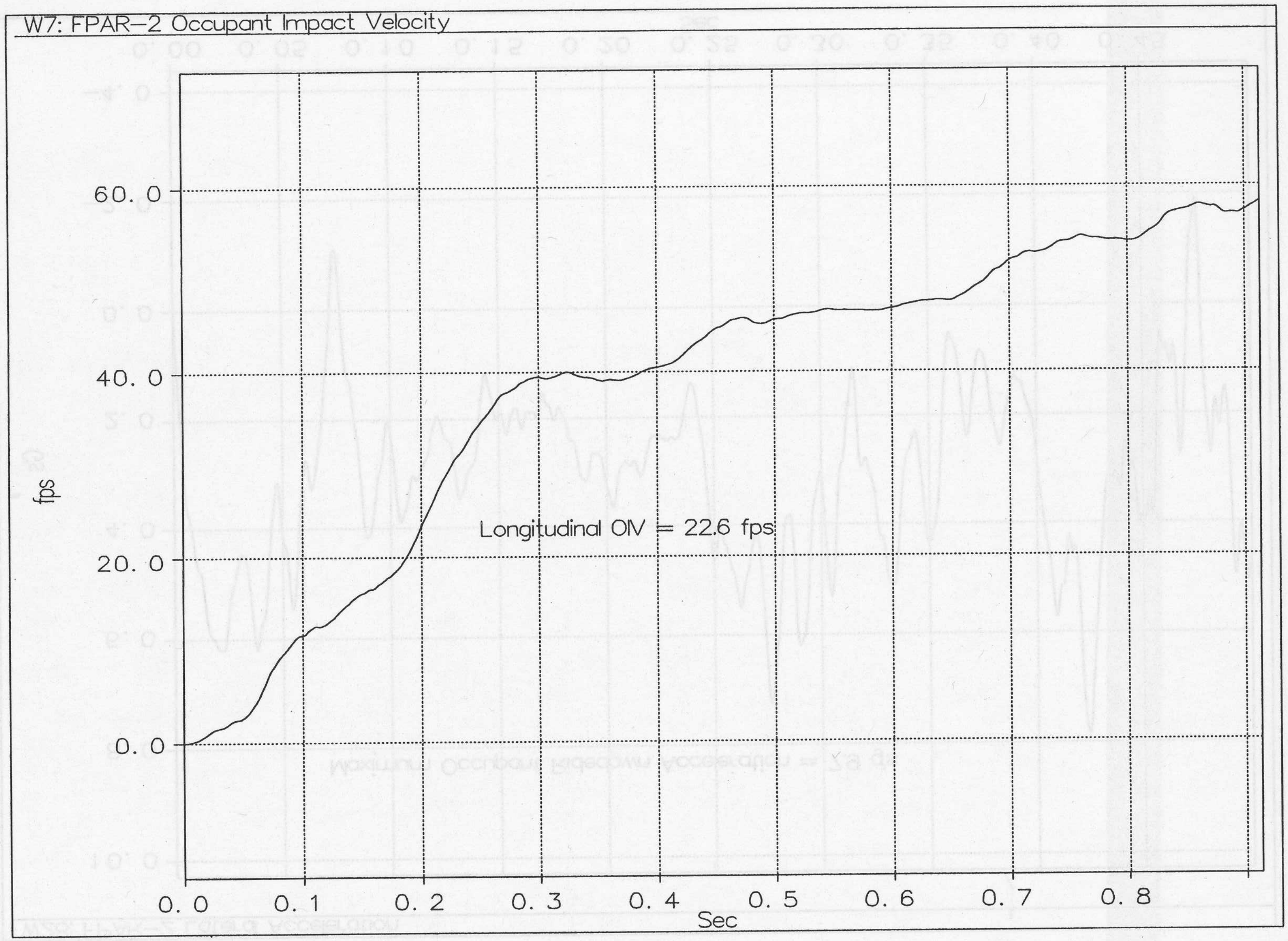


Figure A-2. Graph of Longitudinal Occupant Impact Velocity

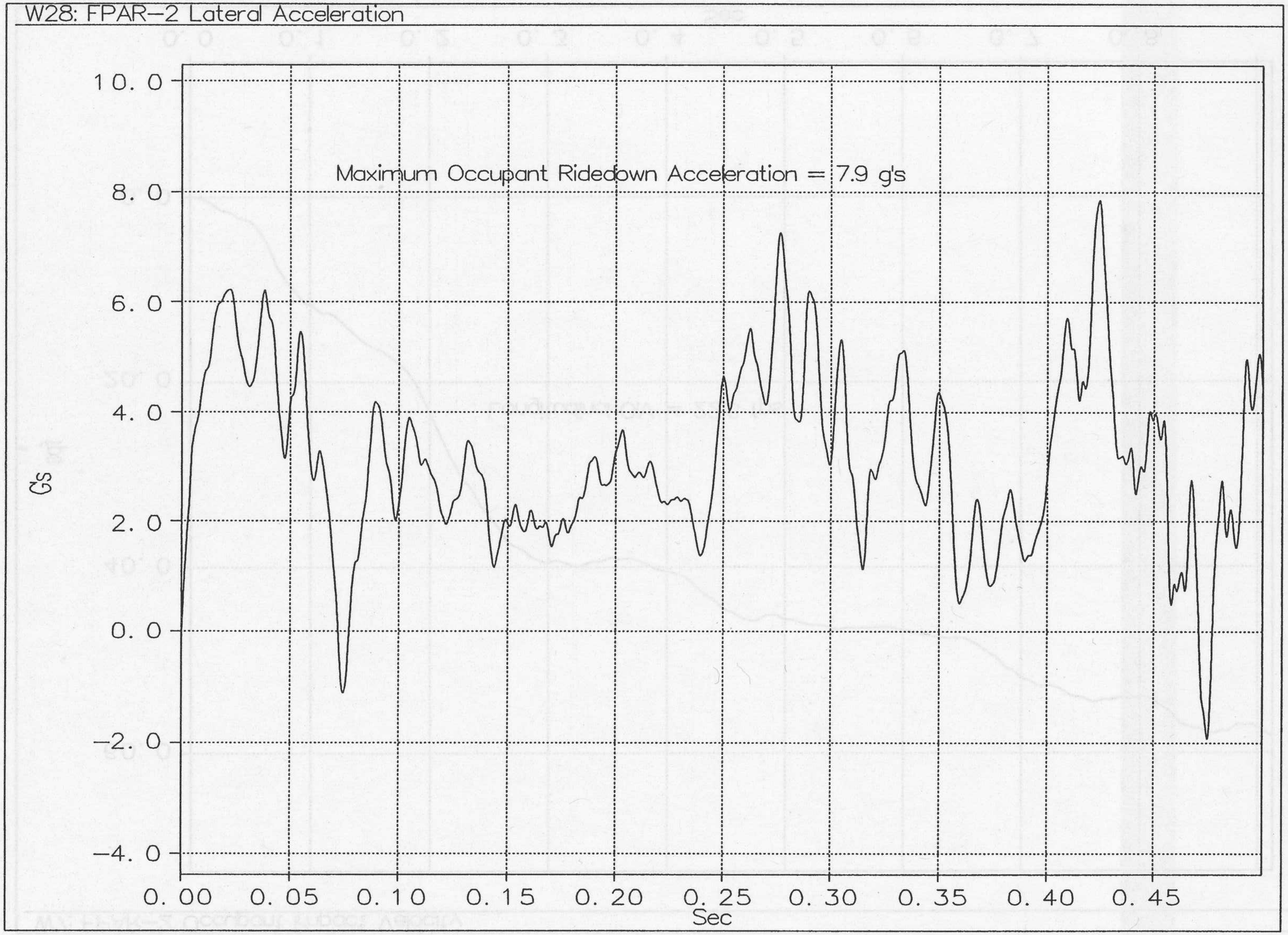


Figure A-3. Graph of Lateral Deceleration

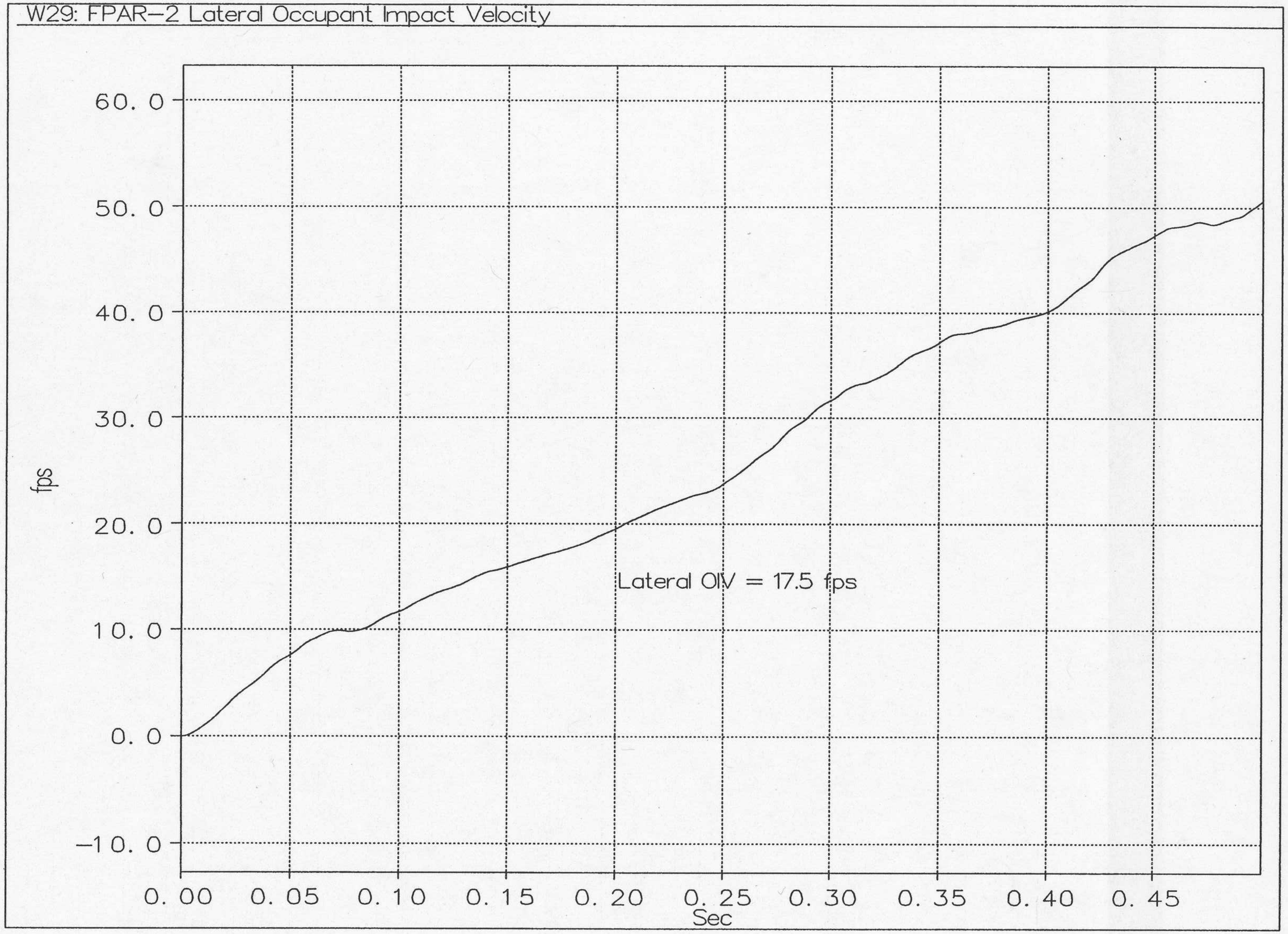


Figure A-4. Graph of Lateral Occupant Impact Velocity