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Safety Performance Evaluation of the George Washington Memorial Parkway Bridge Rail

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DISCLAIMER STATEMENT

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ABSTRACT

Three full-scale crash tests were conducted on the George Washington Memorial Parkway bridge rail. The bridge rail is constructed with three steel tube rails supported by steel posts spaced on 7 ft. 9.5 in. (2.38 m) centers, and mounted on an 8 in. (20.3 cm.) curb. The first test consisted of an 1850 lb (839 kg) minicompact car impacting at a speed of 54.4 mph (87.5 km/h) and an angle of 21.0 degrees. Following an unsuccessful test, the bridge rail was redesigned. The rail was first retested using a 1750 lb (794 kg) minicompact car which impacted at 52.6 mph (84.7 km/h) and 22.6 degrees. This test passed the required safety criteria, so the final test was conducted with a 5400 lb pickup truck impacting at 46.6 mph (73.5 km/h) and 22.7 degrees.

The tests were evaluated according to the performance level 1 (PL-1) criteria for bridge railings presented in the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings*. They were conducted and reported in accordance with requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*. The performance of the George Washington Memorial Parkway bridge rail was determined to be acceptable according to the AASHTO PL-1 guidelines.

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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 George Washington Memorial Parkway Bridge Rail (GWMPBR) was included in the second Federal Highway Administration (FHWA) testing program - Guardrail Testing Program II.

1.2 Test Installation

Photographs of the George Washington Memorial Parkway Bridge Rail are shown in Figures 1 and 2. This system consists of ASTM - A588 steel posts mounted on an 8 in. (20.3 cm) curb, supporting three ASTM - A53, Grade B extra strong steel pipe rails. Throughout the course of the safety evaluation of this system, the design was modified once. The original design, shown in Figure 3, was evaluated during Test GWMP-1. The system was modified for Tests GWMP-2 and 3 by changing the diameter of the rail pipe from 4.5 in. to 5.0 in. (114 mm to 127 mm)outside diameter (O.D.), and placing them further away from the post, as shown in Figure 4. 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 5. Grade 60 epoxy coated reinforcement was used in the deck.

1.3 Test Criteria

This bridge rail system was evaluated according to the performance level 1 (PL-1) criteria for bridge railings presented in the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* (3). The full-scale vehicle crash tests were conducted and reported in accordance with requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 230, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* (4).

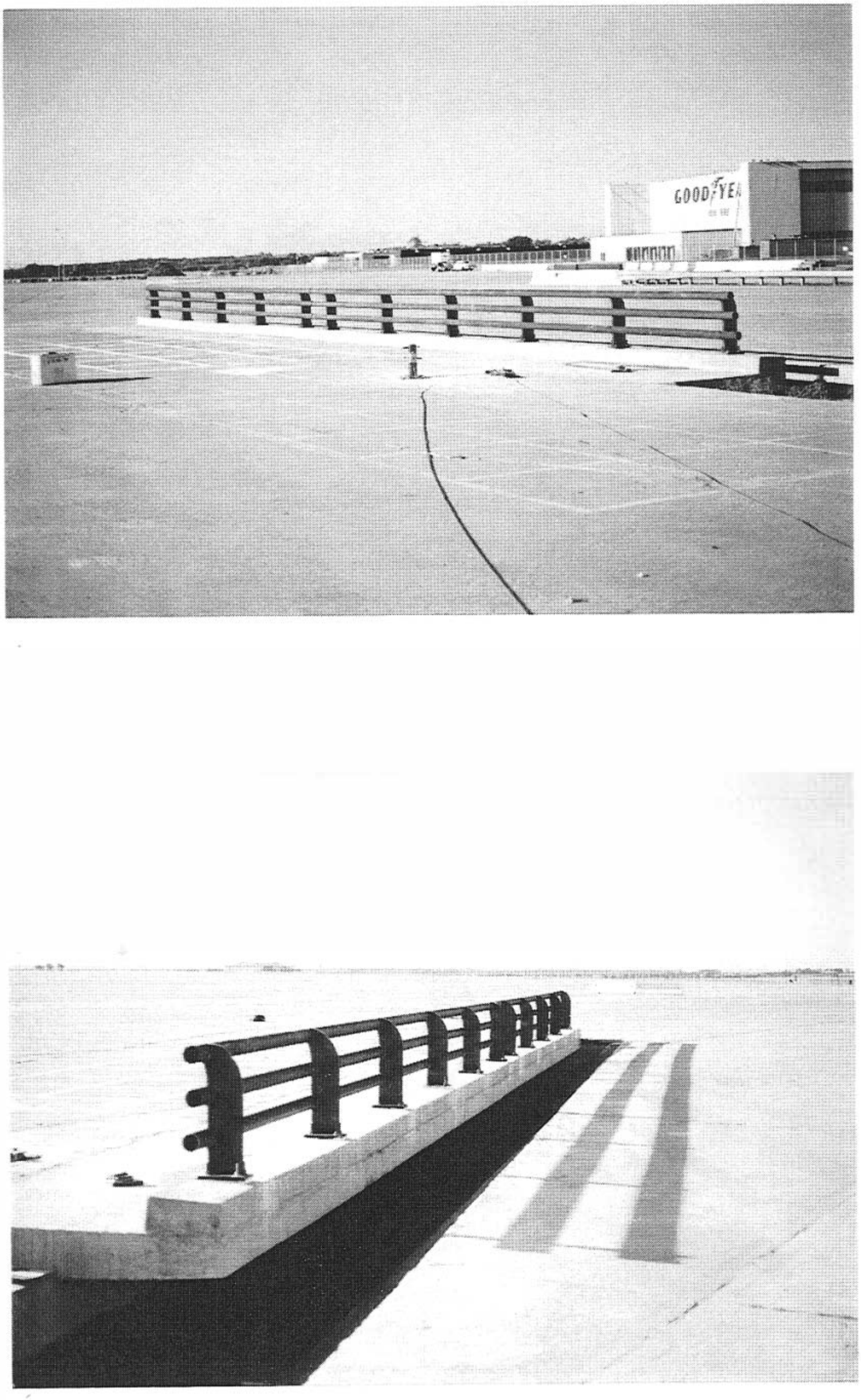
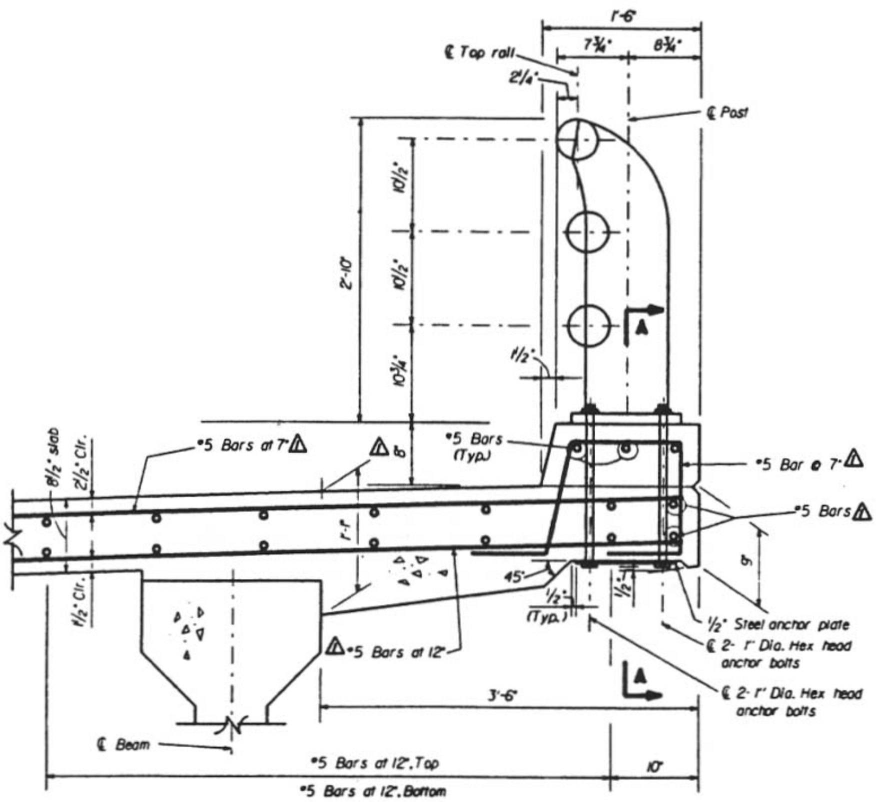
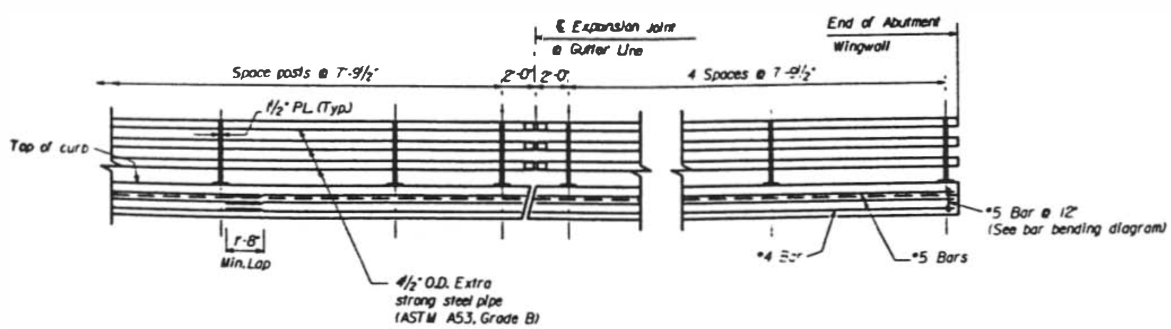


Figure 1. The George Washington Memorial Parkway Bridge Rail.

Figure 2. The George Washington Memorial Parkway Bridge Rail (cont.).

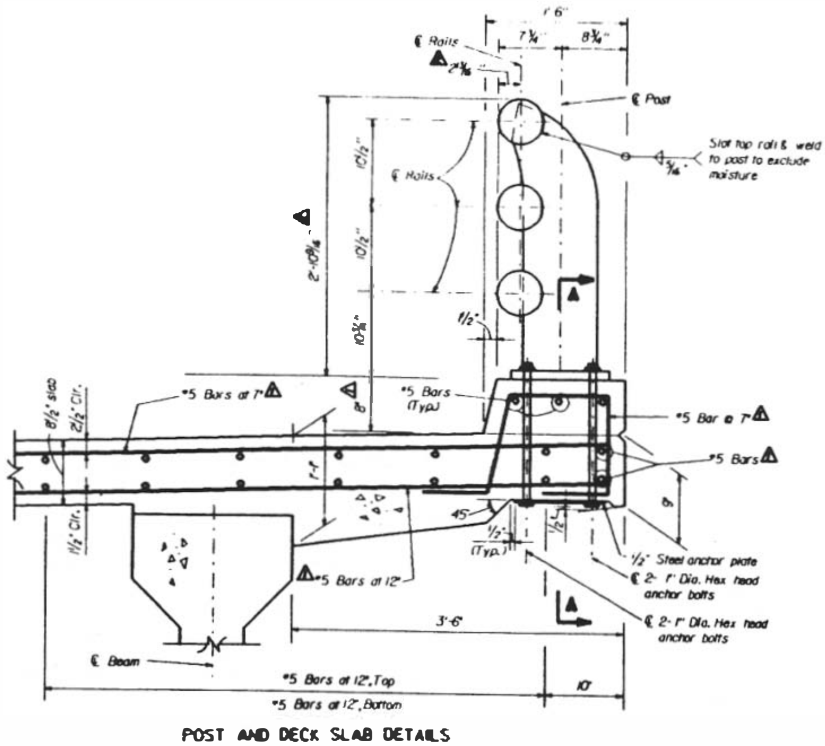


POST AND DECK SLAB DETAILS



RAILING ELEVATION

Figure 3. Design Details of the GWMPBR for Test GWMP-1.



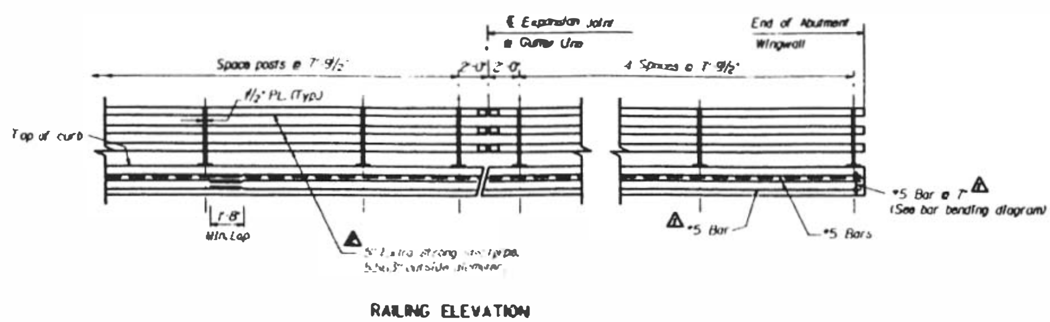


Figure 4. Design Details of the GWMPBR for Tests GWMP-2 and 3.

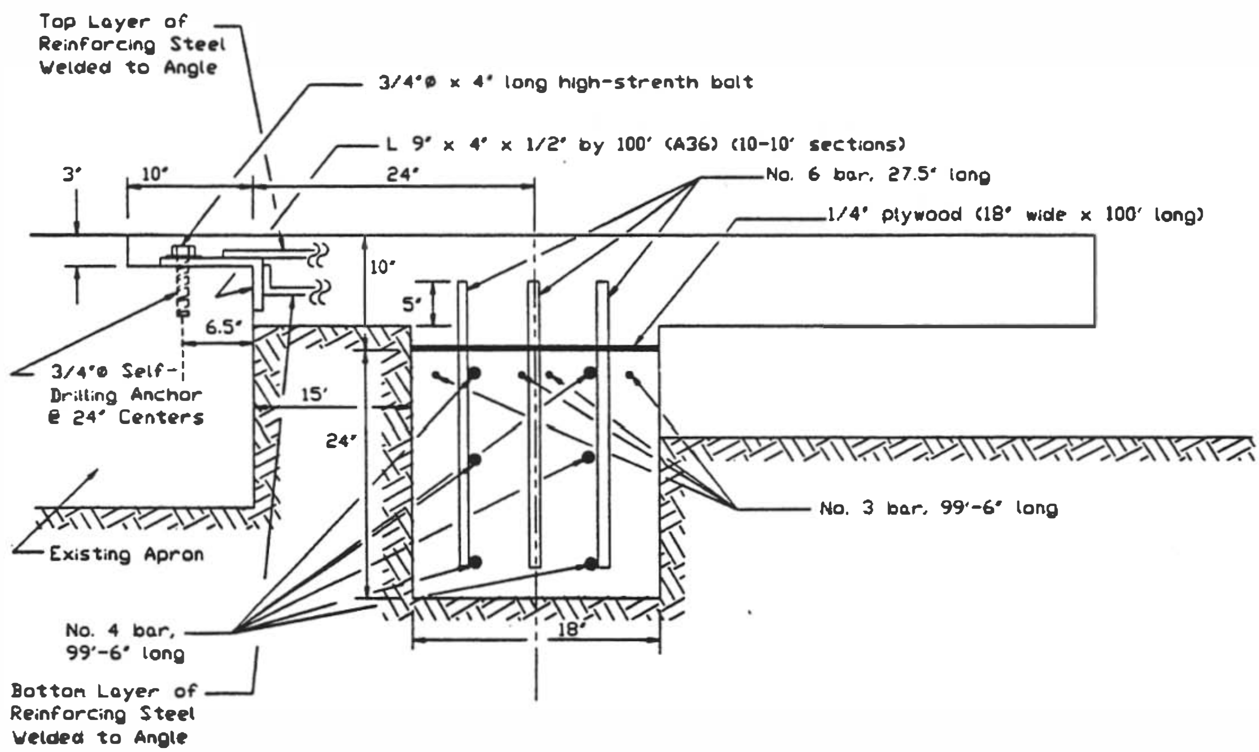


Figure 5. Cross-section of the simulated concrete deck.

2. TEST CONDITIONS

2.1 Test Vehicles

A 1984 Dodge Colt, shown in Figure 6, was used as the test vehicle for Test GWMP-1. As shown in Figure 7, the vehicle had a test inertial weight of 1850 lbs (839 kg).

A 1984 Dodge Colt, shown in Figure 8, was used as the test vehicle for Test GWMP-2. As shown in Figure 9, the vehicle had a test inertial weight of 1750 lbs (794 kg).

A 1985 Chevrolet 3/4-ton pickup, shown in Figure 10, was used as the test vehicle for Test GWMP-3. As shown in Figure 11, the vehicle had a test inertial weight of 5400 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 the 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 6. Test Vehicle, Test GWMP-1.

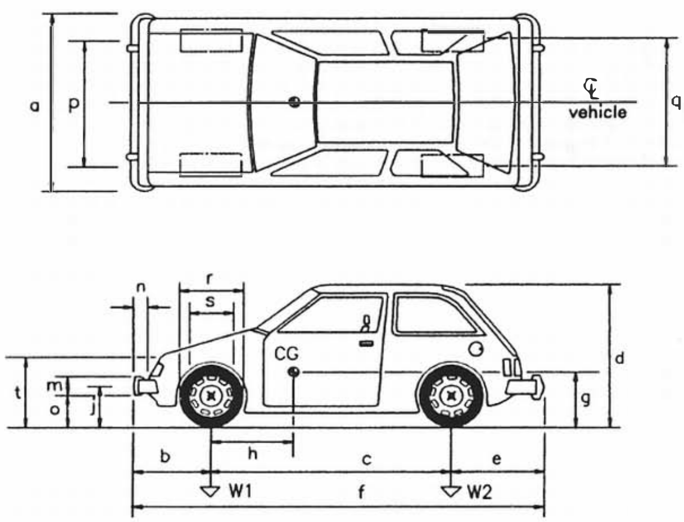
Make: Dodge Test No.: GWMP-1

Model: Colt Tire Size: P155/80R13

Year: 1984 VIN: JB3BE24A9EU104612

Vehicle Geometry
Inches

a —	58.0	b —	32.5
c —	90.5	d —	53.0
e —	31.5	f —	154.5
g —	19.5	h —	30.5
j —	17.0	m —	4.5
n —	6.0	o —	15.0
p —	54.0	q —	53.5
r —	22.5	s —	14.25
t —	31.0		



Engine Size: 4 cyl.

Transmission: manual

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	1175	1225	1305
W2	625	625	705
Wtotal	1800	1850	2010

Moment of Inertia ($lb-sec^2-in$) – Gross Static

Roll (Ix)	1299.0
Pitch (Iy)	5628.0
Yaw (Iz)	9119.0

Damage prior to test: SEE PHOTOS

Figure 7. Test Vehicle Dimensions, Test GWMP-1.

Figure 8. Test Vehicle, Test GWMP-2.

Make: Dodge

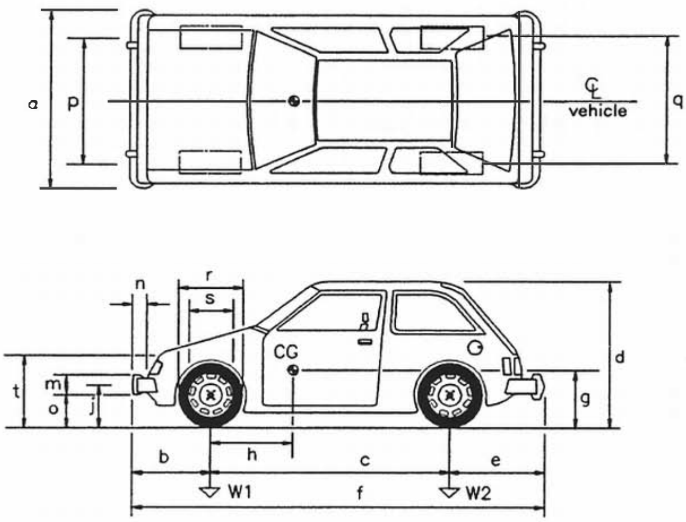
Test No.: GWMP-2

Model: Colt

Tire Size: P155/80R13

Year: 1984

VIN: JB3BE24AXEU119411



Vehicle Geometry
Inches

a	60.0	b	29.9
c	91.5	d	52.5
e	28.5	f	149.5
g	19.5	h	38.0
j	19.4	m	5.0
n	3.5	o	16.9
p	53.6	q	53.0
r	22.5	s	14.5
t	30.25		

Engine Size: 4 cyl.

Transmission: manual

Weight (lbs)	Curb	Test Inertial	Gross Static
W1	1175	1068	1162
W2	625	708	774
Wtotal	1800	1776	1936

Moment of Inertia (lb−sec^2−in) − Gross Static

Roll (Ix)	NA
Pitch (Iy)	NA
Yaw (Iz)	NA

Damage prior to test: SEE PHOTOS

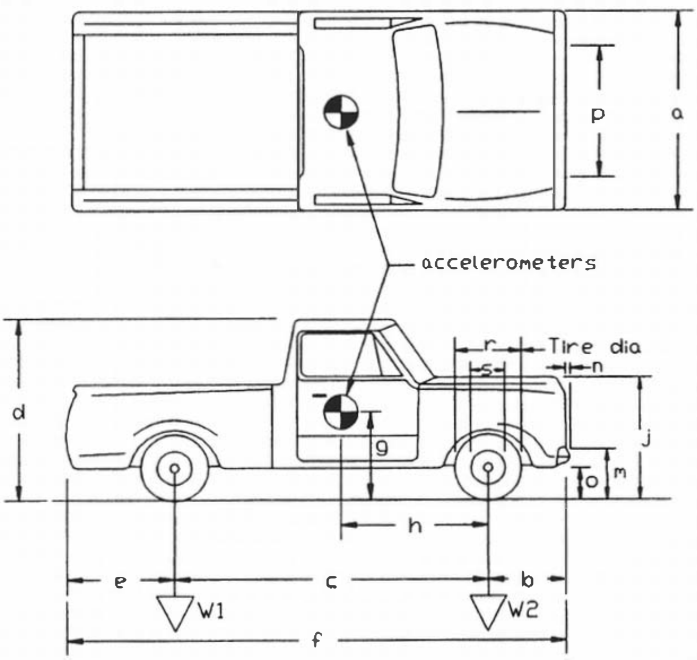
Figure 9. Test Vehicle Dimensions, Test GWMP-2.

Figure 10. Test Vehicle, Test GWMP-3.

Date: 3/24/94 Test No.: GWMP-3 Vehicle I.D. #: 1GBGC24M6FJ170210

Make: Chevrolet Model: C-20 3/4 ton Pickup

Tire Size: 235/85R16 Year: 1985 Odometer: Exceeds Mech. Limits



Vehicle Geometry - inches

a	77	b	32
c	131.5	d	71.5
e	52.0	f	215.5
g	—	h	67.5
i	—	j	44.5
k	—	l	—
m	25.5	n	4.0
o	16.5	p	65.75
r	30.5	s	17.5

Engine Type: 8 cyl.

Engine Size: 350 cu. in.

Transmission Type:

(Automatic) or Manual

FWD or (RWD) or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1950	2610	2528
W2	2490	2950	2872
Wtotal	4440	5560	5400

Note any damage prior to test: none

Figure 11. Test Vehicle Dimensions, Test GWMP-3.

2.2 Data Acquisition Systems

2.2.1 Accelerometers

Two triaxial piezoresistive accelerometer systems with a range of ±200 g's (Endevco Model 7264) were used to measure vehicle accelerations. The accelerometers were rigidly attached to an aluminum block mounted near the vehicle's center of gravity. Accelerometer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted to a Honeywell 101 Analog Tape Recorder.

For tests GWMP-2 and GWMP-3, one backup triaxial piezoresistive accelerometer system with a range of ±200 G's was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was configured with 256 Kb of RAM memory and a 1,120 Hz filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP" were used to digitize, analyze, and plot the accelerometer data.

2.2.2 High Speed Photography

Four high-speed 16-mm cameras operating at 500 frames/sec were used to film the crash tests. A Red Lake Locam camera with a 12.5 mm lens was placed above the test installation to provide a overhead view of the test. A Photec IV, with an 80-mm lens, was placed downstream from the impact point and had a field of view parallel to the barrier. A second Photec IV, with a 55-mm lens, was placed on the traffic side of the bridge rail and had a field of view perpendicular to the barrier. A Hi-G Red Lake Locam camera with a 5.7-mm lens was placed onboard the vehicle to record dummy motions during the test. A schematic of the camera locations for each test is shown in Figure 12. A white-colored 5-ft. by 5-ft. (1.52 m by 1.52 m) grid was painted on the concrete in front of the rail in view of the overhead camera. This grid provided a visible reference system to use in the analysis of the overhead high-speed film. The film was analyzed using a Vanguard Motion Analyzer.

2.2.3 Speed Trap

Seven tape pressure switches spaced at 5-ft. (1.52 m) intervals were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light and sent an electronic timing mark to the data acquisition system as the left front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded on "Computerscope" software. Strobe lights and high speed film analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

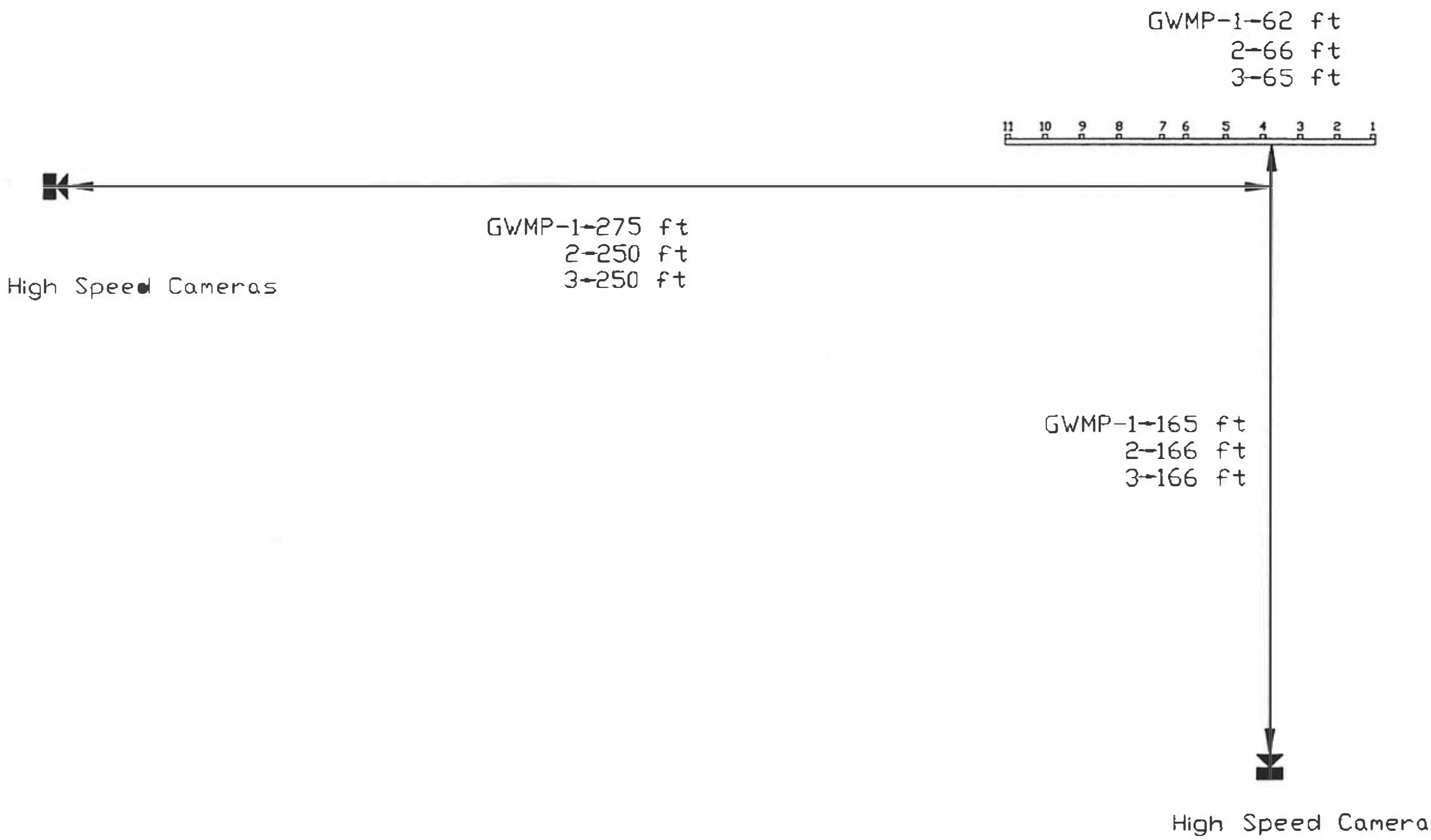


Figure 12. Layout of High-Speed Cameras.

3. TEST RESULTS

3.1 Test GWMP-1

The 1984 Dodge Colt was directed into the George Washington Memorial Parkway Bridge Rail using a reverse tow and cable guidance system (5). 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 54.4 mph (87.5 km/h) and the angle of impact was 21.0 degrees. As shown in Figure 13, the impact point was located midway between the 3rd and 4th posts from the upstream end of the installation. A summary of the test results and sequential photographs are shown in Figure 14. Additional sequential photographs are shown in Figure 15.

Upon impact with the steel bridge rail, the right front quarter panel was crushed inward and the bumper was pulled to the right and pushed back causing the front end of the vehicle to bend toward the right side of it's longitudinal centerline. 42 ms after impact the bumper began to contact post number 4 and was crushed into the front right tire. With the bumper pushing the tire into the firewall, the vehicle began to buckle at the door post. This caused the windshield frame and roof to buckle. At 116 ms the car lost contact with post number 4 and continued down the rail with no further snagging. There was no rolling motion detected throughout the collision, and the vehicle was redirected, coming to rest 170 ft. (51.8 m) downstream and 90 ft. (27.4 m) behind a line parallel to the rail face, as shown in Figure 16.

The vehicle damage, shown in Figures 17 and 18, included the crushing of the right front corner of the vehicle, twisting of the car to the right of its longitudinal centerline, buckling of the hood, roof, windshield frame, firewall, passenger compartment floor and the passenger side door. The front right tire was deflated and the rim was deformed. The maximum crush deformation of 21 in. (53.3 cm) is shown in Figure 19.

The damage to the bridge rail was minor, with superficial scrapes on the curb, rail and posts as shown in Figure 20. There was no permanent set deflection in the bridge rail. The contact marks on the curb started at impact, 4 ft. - 5 in. (1.35 m) before post 4, and continued for 11 ft. - 8 in. (3.56 m). Contact with the lower rail began 4 ft. - 0 in. (1.2 m) before post 4 and continued for 19 ft. - 6 in. (5.94 m), and contact with the middle rail began 3 ft. - 8 in. (1.12 m) before post 4 and continued for 17 ft. - 0 in. (5.18 m).

As a result of technical problems, the accelerometer data was not acquired for this test. It was therefore necessary to analyze the high-speed film to determine the values of the occupant risk criteria. The longitudinal and lateral occupant impact velocities as determined from this high speed film analysis were 24.6 and 8.2 fps, respectively. The maximum occupant ridedown decelerations were 12.0 g's (longitudinal) and 22.4 g's (lateral). The results of this analysis are summarized in Figure 14 and Table 1.

As is evident in the vehicle damage shown in Figures 17 and 18, there was significant occupant compartment damage in the test vehicle. This damage was caused by the snagging of the vehicle on the system posts and, along with the excessive lateral ridedown decelerations, caused the system to fail this compliance test. In order to alleviate this snagging problem, the rail size was increased from 4.5 in. O.D. to 5.0 in. O.D. (114 mm to 127 mm), and it was moved further out from the post. The details of this change can be seen in Figures 3 and 4.

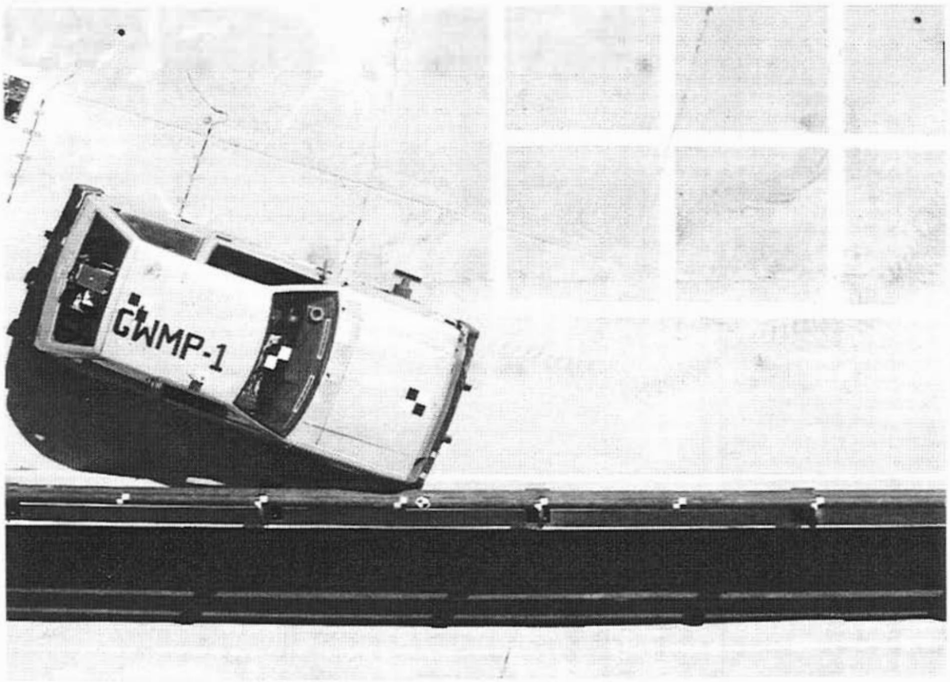
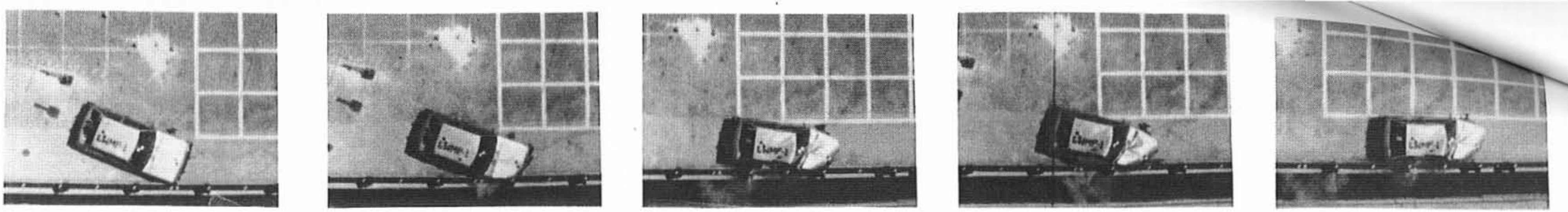
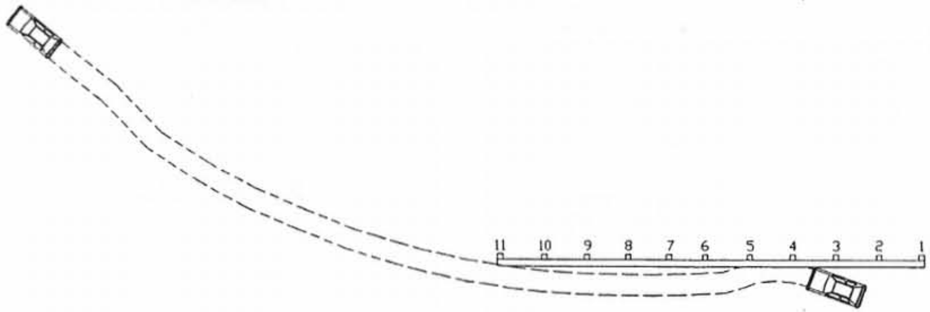


Figure 13. Impact Location, Test GWMP-1.



Impact | 50 ms | 100 ms | 180 ms | 300 ms

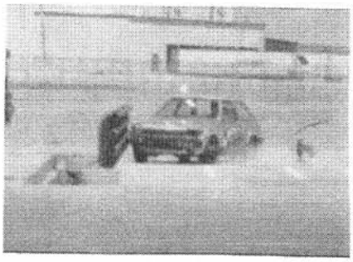


Test Number	GWMP-1
Federal Contract No.	DTFH71-90-C-00035
Date	8/04/93
Installation	George Washington Memorial Parkway
Bridge Rail	
Length	75 ft.
Height from curb	2 ft.- 10 in.
Post spacing	7 ft.- 9.5 in.
Material	
Post	ASTM - A588
Rail	ASTM - A53, Grade B ESSP, 4.5 O.D.
Curb	
Height	8 in.
Top width	1 ft.- 4.5 in.
Bottom width	1 ft.- 6 in.
Vehicle Model	1984 Dodge Colt
Vehicle Weight	
Curb	1700 lb
Test Inertia	1850 lb
Gross Static	2010 lb

Speed	
Impact	54.4 mph
Exit	38.9 mph
Angle	
Impact	21.0 deg
Exit	3.8 deg
Occupant Impact Velocity	
Longitudinal	24.6 fps
Lateral	8.2 fps
Occupant Ridedown Deceleration	
Longitudinal	12.0 g's
Lateral	22.4 g's
Vehicle Damage	
TAD	1-RFQ-6
VDI	01RFES3
Vehicle Rebound Distance	22 in. @ 40 ft.
Bridge Rail Damage	Superficial
Maximum Permanent Set Deflection	0 in.

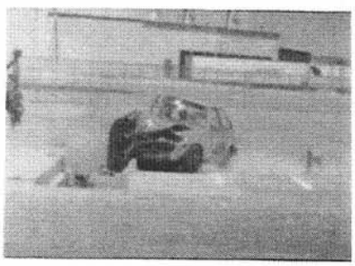
Conversion Factors: 1 in.= 2.54 cm; 1 lb= 0.454 kg

Figure 14. Summary of Test GWMP-1.

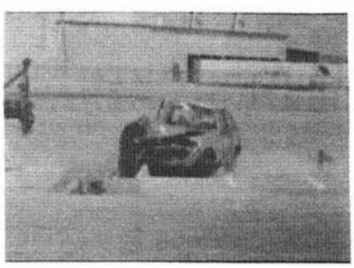


Impact

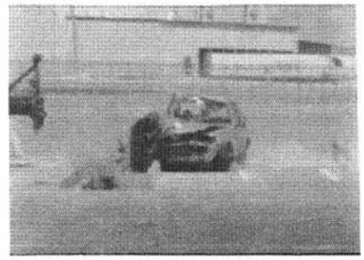
50 ms



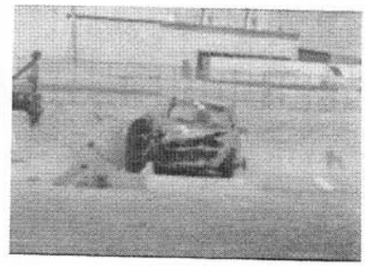
100 ms



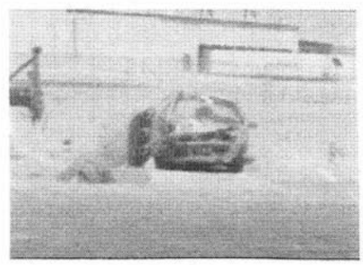
150 ms



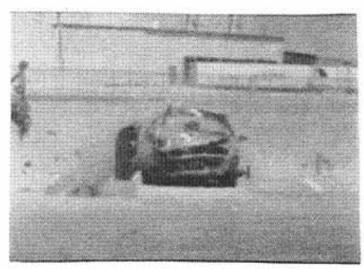
200 ms



300 ms



400 ms



500 ms

Figure 15. Downstream Sequential Photographs, Test GWMP-1.

Figure 16. Vehicle Trajectory, Test GWMP-1.

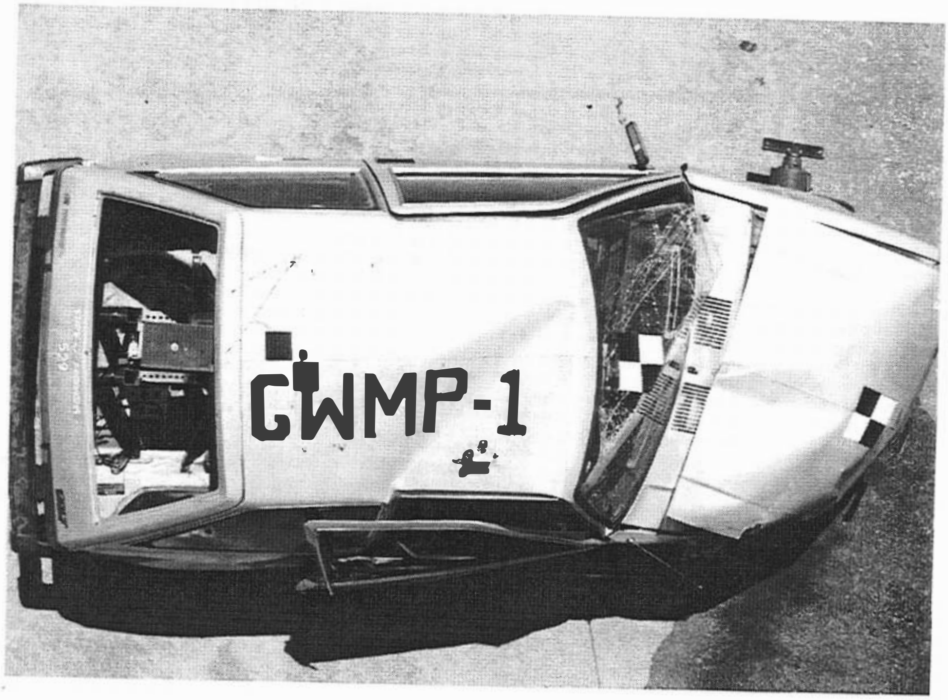


Figure 17. Vehicle Damage, Test GWMP-1.

Figure 18. Vehicle Damage, Test GWMP-1 (cont.).

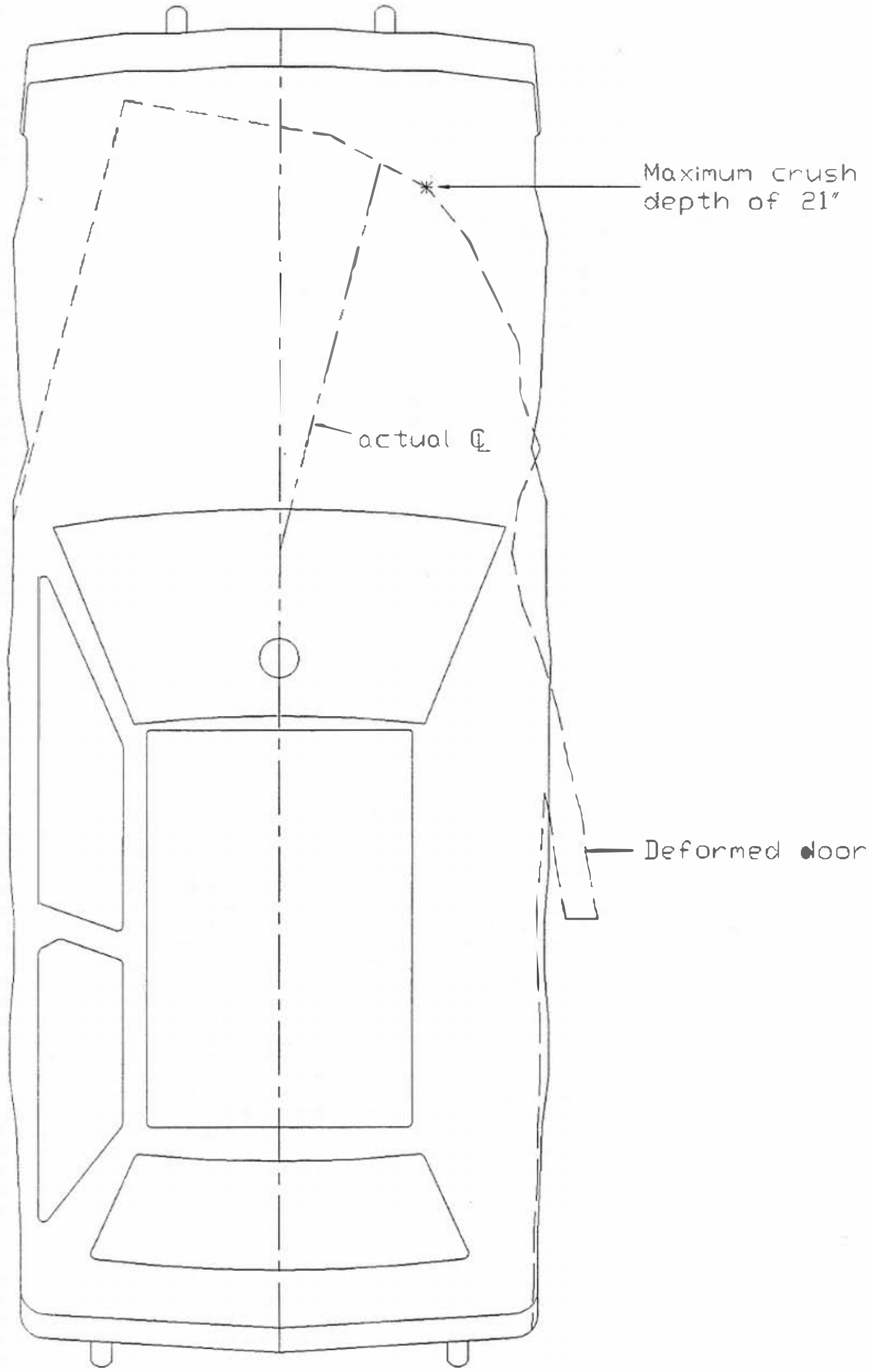


Figure 19. Vehicle Crush Measurements, Test GWMP-1.

Figure 20. Bridge Rail Damage, Test GWMP-1.

3.2 Test GWMP-2

The 1984 Dodge Colt was directed into the George Washington Memorial Parkway Bridge Rail using a reverse tow and cable guidance system (5). 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 52.6 mph (84.65 km/h) and the angle of impact was 22.6 degrees. The impact point was located midway between the 3rd and 4th posts from the upstream end of the installation as shown in Figure 21. A summary of the test results and sequential photographs is shown in Figure 22.

Upon impact with the bridge rail system, the right front corner of the car was crushed inward. 68 ms after impact, the right front corner of the hood contacted post 4 causing the hood to rotate about its right front mount in a clockwise manner, approximately 90 degrees. The vehicle continued down the rail without the tire mounting the curb. When the vehicle approached post 5, 174 ms after impact, the left front corner of the hood contacted post 5 separating it from the vehicle. The hood remained at post 5 between the upper and middle rails as the vehicle proceeded down the rail. The hood then made contact with right front windshield support and the lower right corner of the windshield and was forced up and over the vehicle. The vehicle came to rest 120 ft. (36.5 m) downstream of impact and 61 ft. (18.6 m) In front of a line parallel with the front face of the bridge rail as seen in Figure 23.

The vehicle damage, shown in Figures 24 and 25, included crushing of the front right corner of the vehicle, minor scrapes and dents along the length of the passenger side, and separation of the hood. The windshield was not penetrated but did sustain localized cracking in the lower right corner. The front right tire was blown out and the rim was bent outward at the top. The occupant compartment floor sustained minor buckling in the front passenger side floor area. The maximum crush deformation of 12 in. (30.5 cm) is shown in Figure 26.

As shown in Figure 27, the bridge rail and curb sustained minor scrapes in the area which the impact occurred. Contact with the middle and lower rail began at the midspan between posts 4 and 5, and continued to the midspan between posts 3 and 4.

The longitudinal and lateral occupant impact velocities were 17.0 fps and 25.7 fps, respectively. The maximum occupant ridedown decelerations were 5.2 g's (longitudinal), and 9.6 g's (lateral). The results of this analysis are summarized in Figure 22 and Table 1. As can be seen, the only criteria which wasn't met in this test was the one which required that the vehicle move no more than 20 ft. (6.1 m) from the line of the traffic face of the railing. However, it was judged that failure of this criteria alone did not warrant failure of the entire test.

It was therefore determined that the overall performance of this test was acceptable according to the AASHTO (3) PL-1 guidelines.

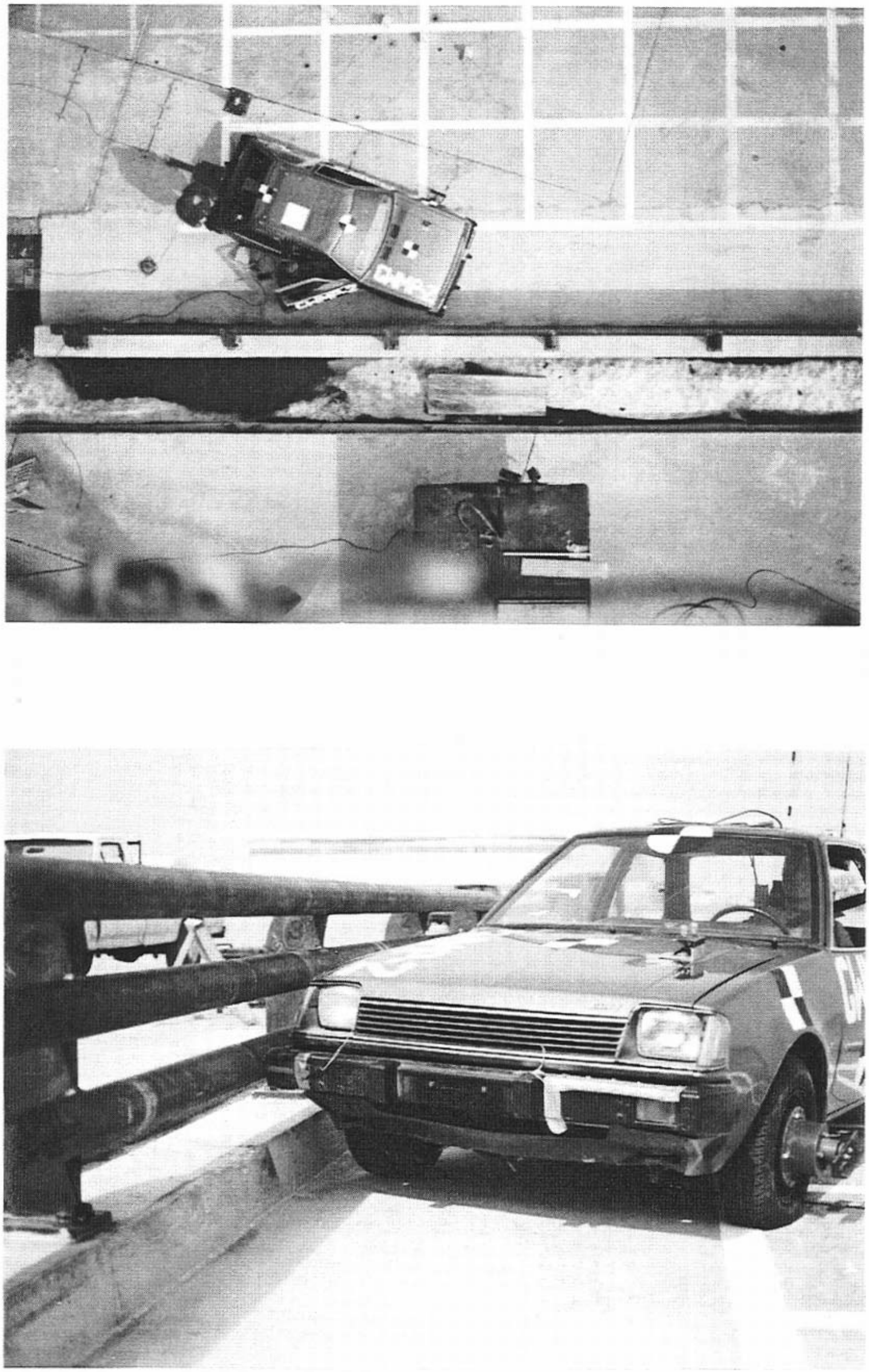
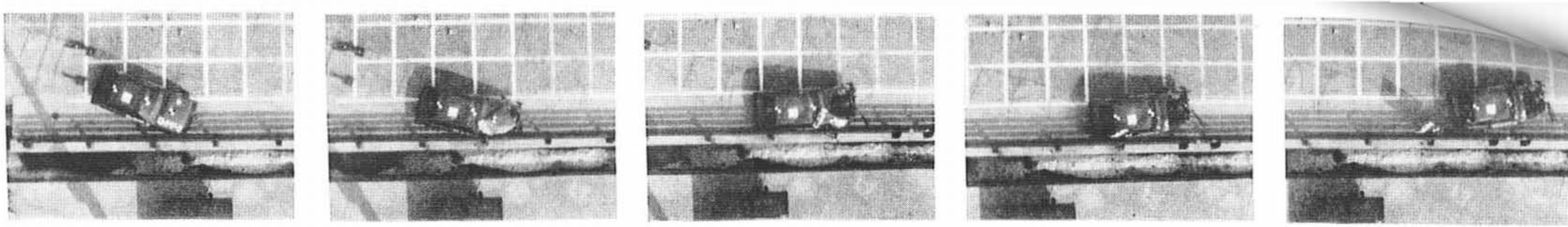
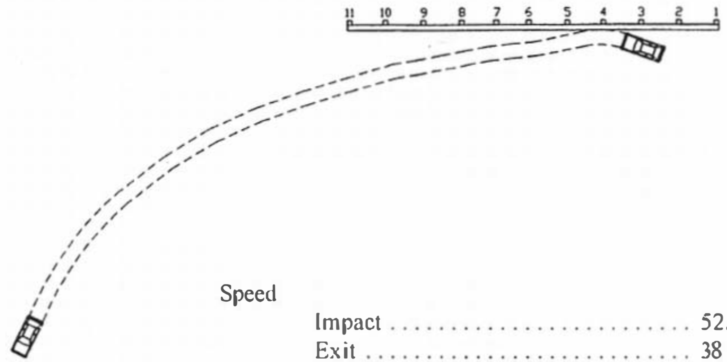


Figure 21. Impact Location, Test GWMP-2.



Impact | 100 ms | 200 ms | 300 ms | 400 ms



Test Number	GWMP-2
Federal Contract No.	DTFH71-90-C-00035
Date	3-08-94
Installation	George Washington Memorial Parkway
Bridge Rail	
Length	75 ft.
Height from curb	2 ft.- 10.5 in.
Post spacing	7 ft.- 9.5 in.
Material	
Post	ASTM - A588
Rail	ASTM - A53, Grade B ESSP, 5 in. O.D.
Curb	
Height	8 in.
Top width	1 ft.- 4.5 in.
Bottom width	1 ft.- 6 in.
Vehicle Model	1984 Dodge Colt
Vehicle Weight	
Curb	1800 lb
Test Inertia	1776 lb
Gross Static	1936 lb

Speed	
Impact	52.6 mph
Exit	38.9 mph
Angle	
Impact	22.6 deg
Exit	6.3 deg
Occupant Impact Velocity	
Longitudinal	17.0 fps
Lateral	25.7 fps
Occupant Ridedown Deceleration	
Longitudinal	5.2 g's
Lateral	9.6 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01FRES2
Vehicle Rebound Distance	39 ft. @ 115 ft.
Bridge Rail Damage	Minor
Maximum Permanent Set Deflection	0.125 in.

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

Figure 22. Summary of Test GWMP-2.

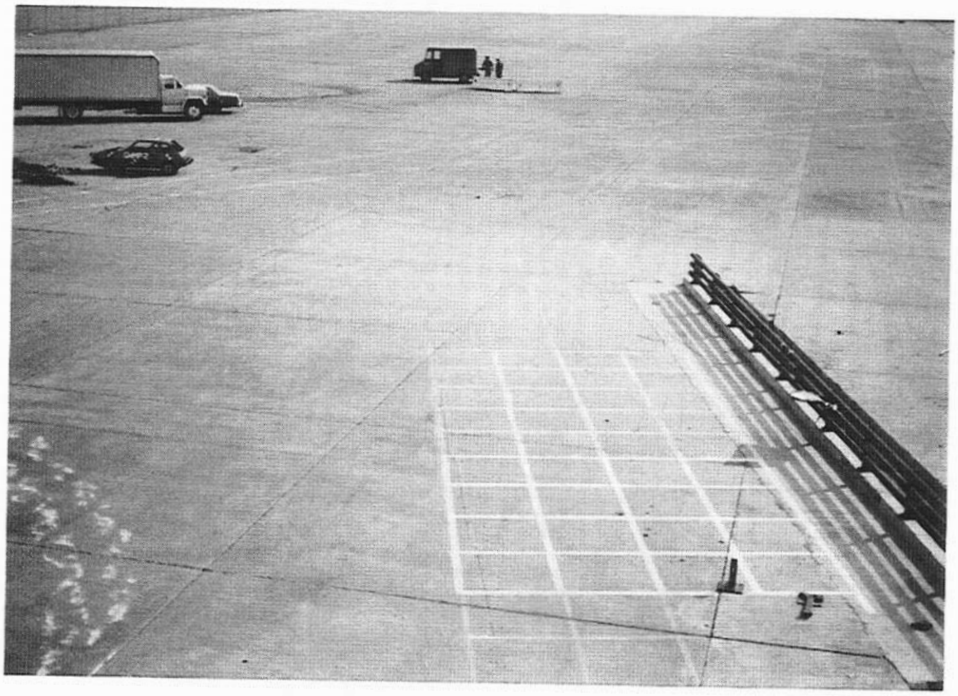
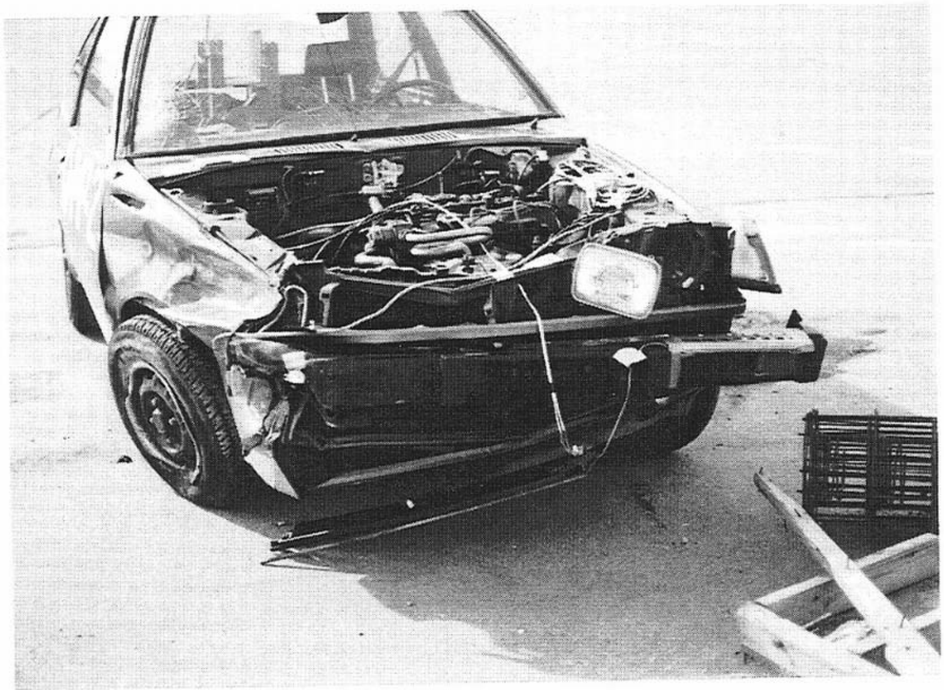


Figure 23. Vehicle Trajectory, Test GWMP-2.

Figure 24. Vehicle Damage, Test GWMP-2.



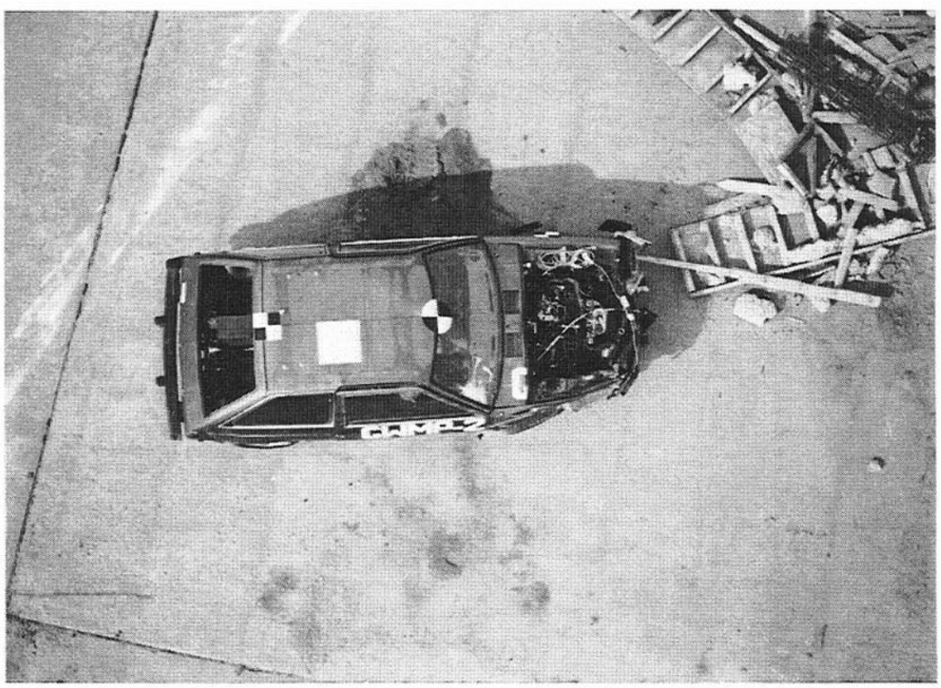


Figure 25. Vehicle Damage, Test GWMP-2 (cont.).

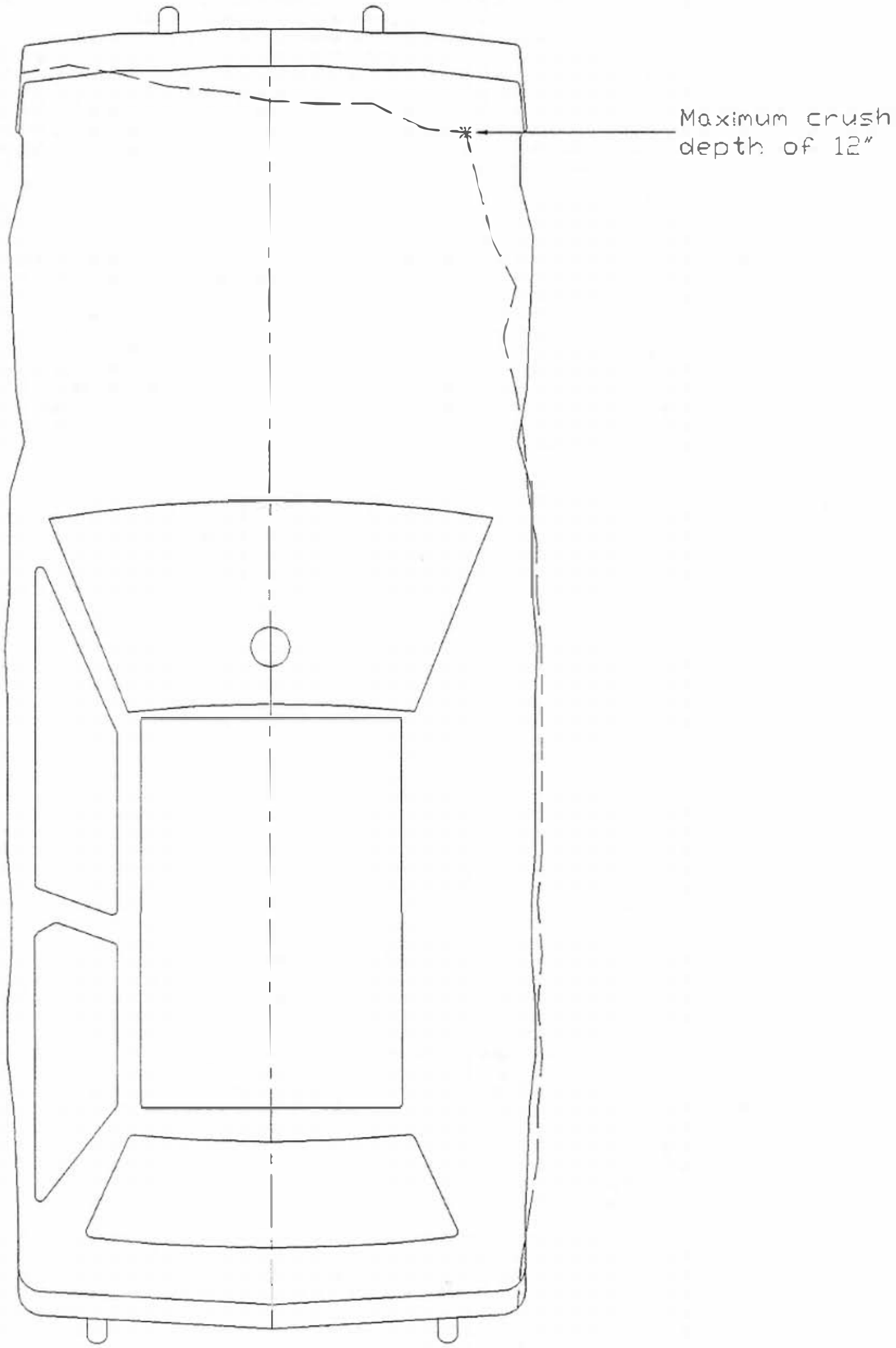
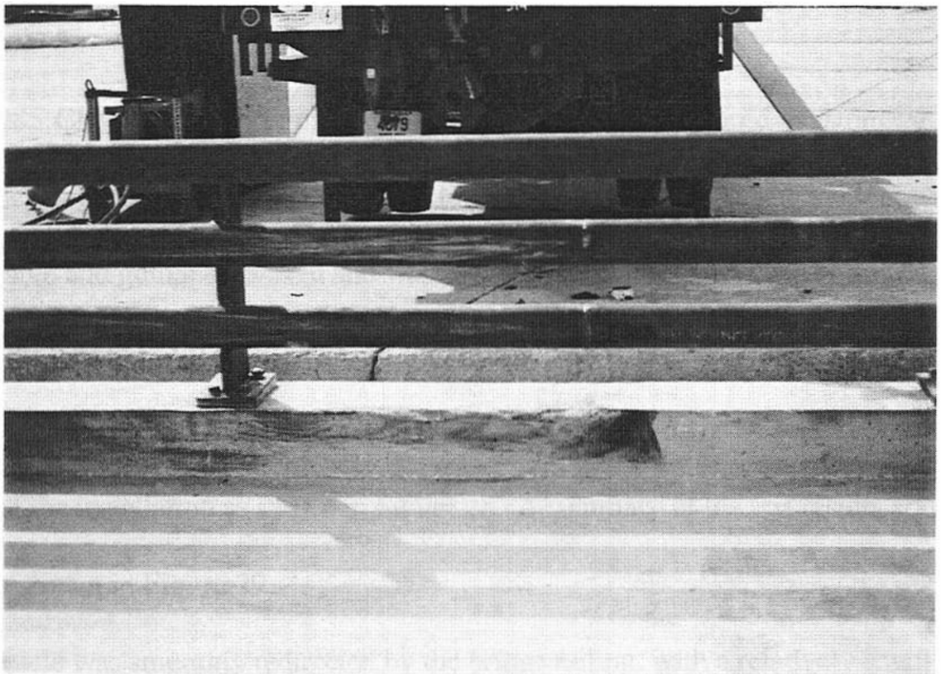


Figure 26. Vehicle Crush Measurements, Test GWMP-2.



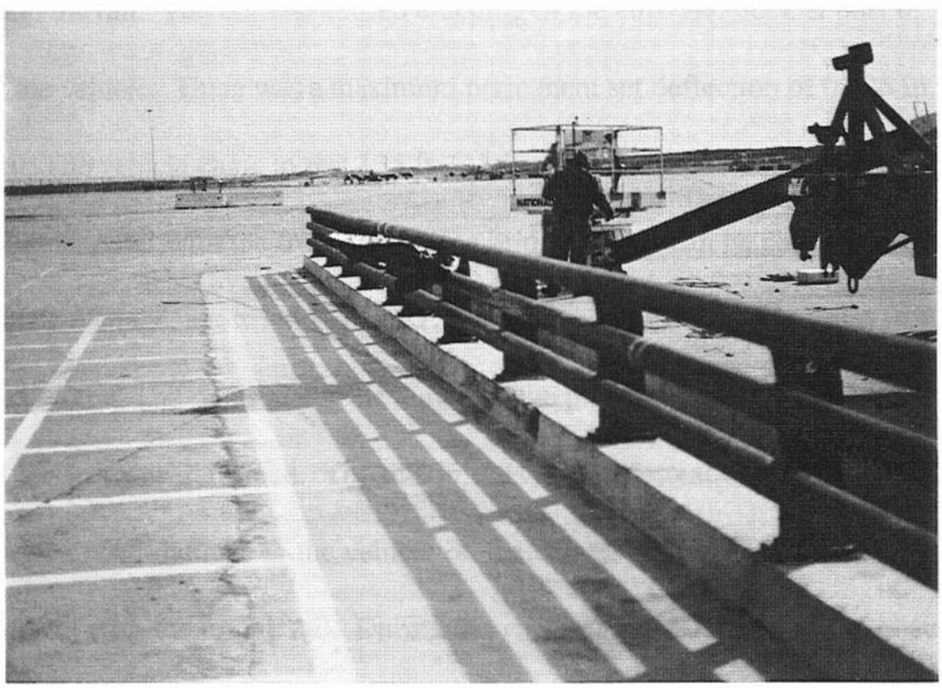


Figure 27. Bridge Rail Damage, Test GWMP-2.

3.3 Test GWMP-3

The 1985 Chevrolet 3/4 ton pickup was directed into the George Washington Memorial Parkway Bridge Rail using a reverse tow and cable guidance system (5). 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 46.6 mph (75.0 km/h) and the angle of impact was 22.7 degrees. The impact point was located 3 ft. - 3.5 in. (1.0 m) upstream of the expansion joint, just before post 6 from the upstream end of the installation as shown in Figure 28. A summary of the test results and sequential photographs is shown in Figure 29.

The vehicle was smoothly redirected by the bridge railing, with a relatively small amount of damage to the vehicle. At 140 ms, tail slap occurred between the passenger side rear quarter panel of the vehicle and the rail. The tail slap caused cracking of the curb and deck at post 6. There was no snagging of the vehicle. There was a maximum permanent set deflection of 0.125 in. (0.32 cm) in the bridge rail. The vehicle came to rest 135 ft. (41.1 m) downstream and 110 ft. (33.5 m) to the back side of a line parallel with the front face of the bridge rail, as can be seen in Figure 30.

The vehicle damage, shown in Figure 31, 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 deformed. The maximum crush deformation of 9.75 in. (24.8 cm) is shown in Figure 32. All damage to the vehicle on the drivers side of the longitudinal centerline occured after impact with the bridge rail. During the vehicle's run out, it struck an obstacle on the testing grounds, which resulted in damage to the left front corner of the vehicle..

The bridge rail sustained only minor cosmetic damage on each of the three rails as shown in Figure 33. Contact with each of the rails began 3 ft. - 5 in. (1.04 m) upstream of the expansion joint.

The vehicle remained in contact with the rail for 8 ft. - 0 in. (2.44 m) on the bottom rail, 8 ft. - 6 in. (2.59 m) on the middle rail, and 8 ft. - 2 in. (2.49 m) on the top rail.

Cracking occured in the curb and bridge deck at post number 6. On top of the curb, two cracks propagated outward from each of the rear post bolts, as shown in Figure 34. The length of cracks upstream and downstream of post 6 were 10 in. (25.4 cm) and 11 in. (27.9 cm) respectively.

The longitudinal and lateral occupant impact velocities as determined from accelerometer data analysis were 9.6 fps (2.93 m/s) and 21.3 fps (6.49 m/s), respectively. The maximum occupant ridedown decelerations were 2.0 g's (longitudinal), and 8.0 g's (lateral). The results of this analysis are summarized in Figure 29 and Table 1.

It was determined that the performance of this test was acceptable according to the AASHTO (3) PL-1 guidelines.

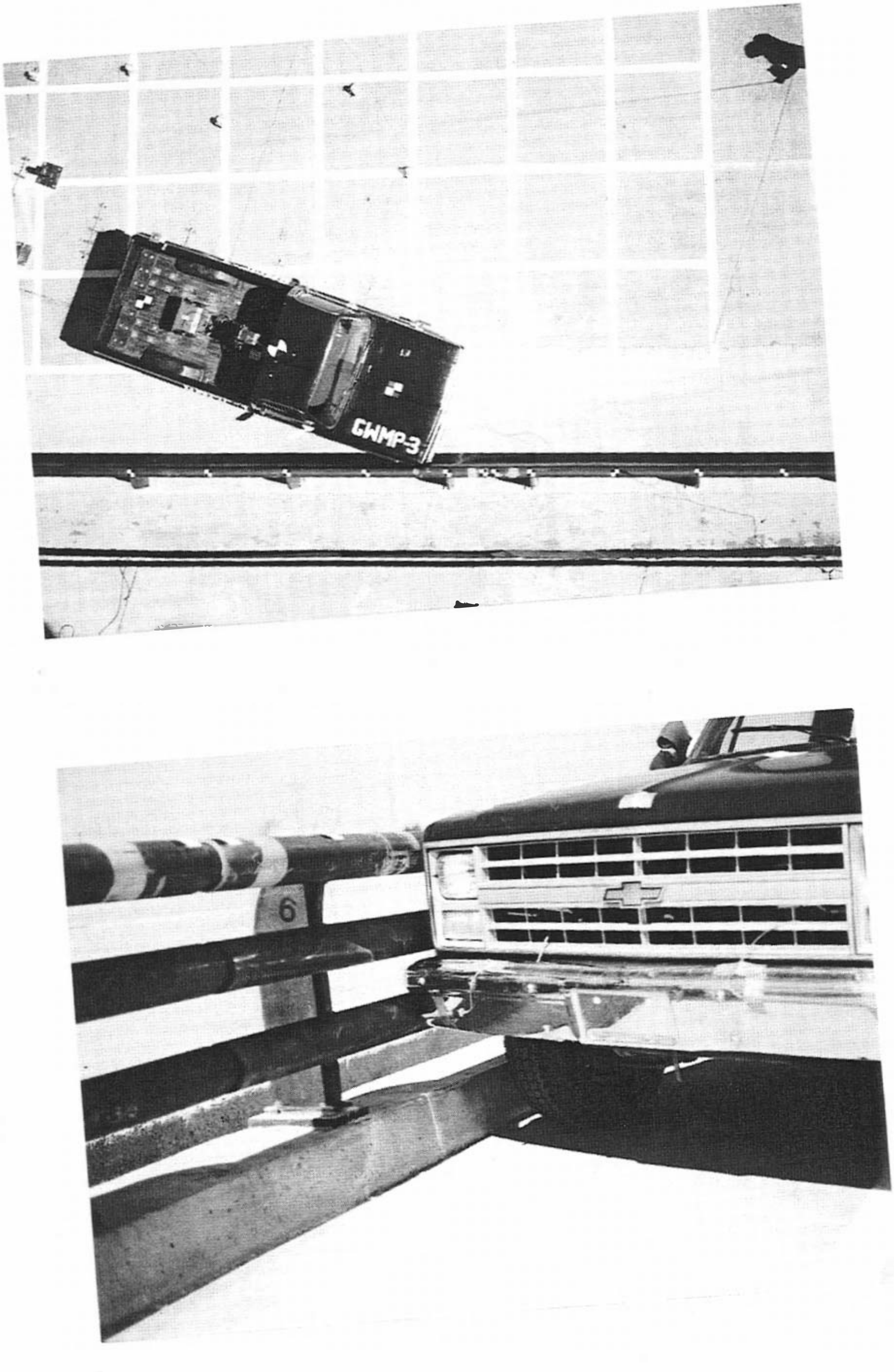
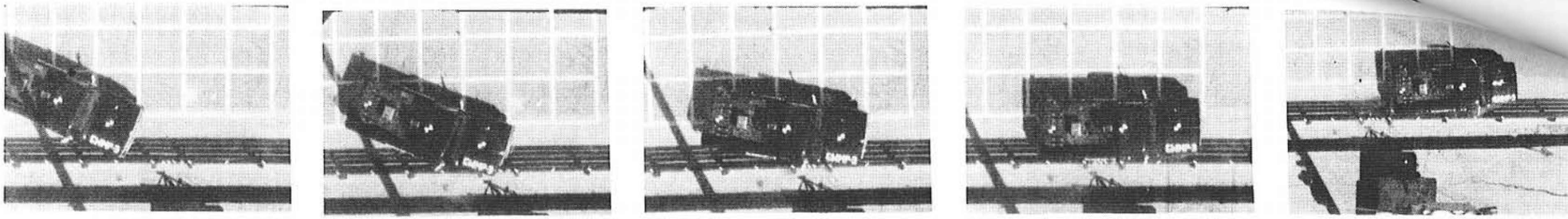
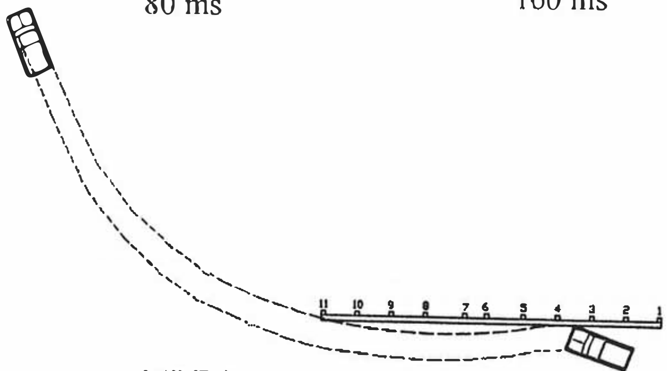


Figure 28. Impact Location, Test GWMP-3.



Impact 80 ms 160 ms 240 ms 410 ms



Test Number	GWMP-3
Federal Contract No.	DTFH71-90-C-00035
Date	3-24-94
Installation	George Washington Memorial Parkway
Bridge Rail	
Length	75 ft.
Height from curb	2 ft.- 10.5 in.
Post spacing	7 ft.- 9.5 in.
Material	
Post	ASTM - A588
Rail	ASTM - A53, Grade B, 5 in. O.D., ESSP
Curb	
Height	8 in.
Top width	1 ft.- 4.5 in.
Bottom width	1 ft.- 6 in.
Vehicle Model	1985 Chevrolet 3/4 ton pickup
Vehicle Weight	
Curb	4440 lb
Test Inertia	5560 lb
Gross Static	5400 lb

Speed	
Impact	46.6 mph
Exit	38.2 mph
Angle	
Impact	22.7 deg
Exit	3.1 deg
Occupant Impact Velocity	
Longitudinal	9.6 fps
Lateral	21.3 fps
Occupant Ridedown Deceleration	
Longitudinal	2.0 g's
Lateral	5.0 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES2
Vehicle Rebound Distance	3 ft. @ 40 ft.
Bridge Rail Damage	Minor
Maximum Permanent Set Deflection	0.25 in.

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

Figure 29. Summary of Test GWMP-3.

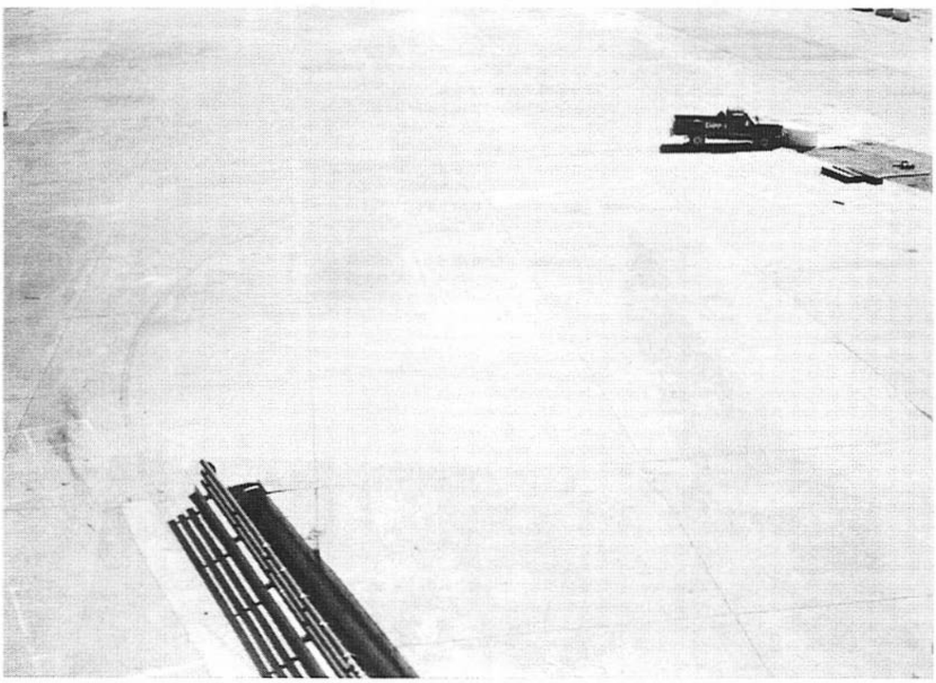


Figure 30. Vehicle Trajectory, Test GWMP-3.

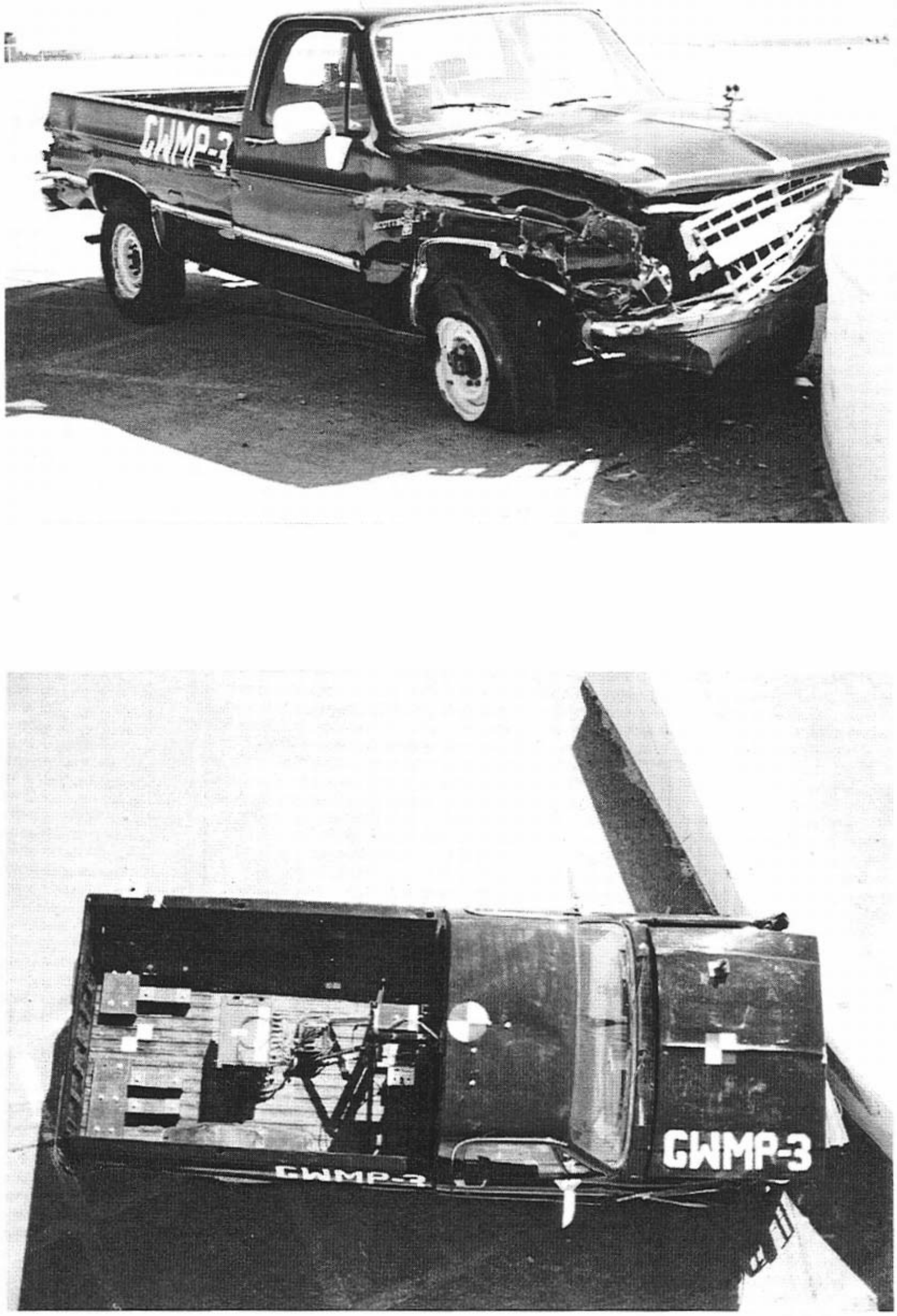


Figure 31. Vehicle Damage, Test GWMP-3..

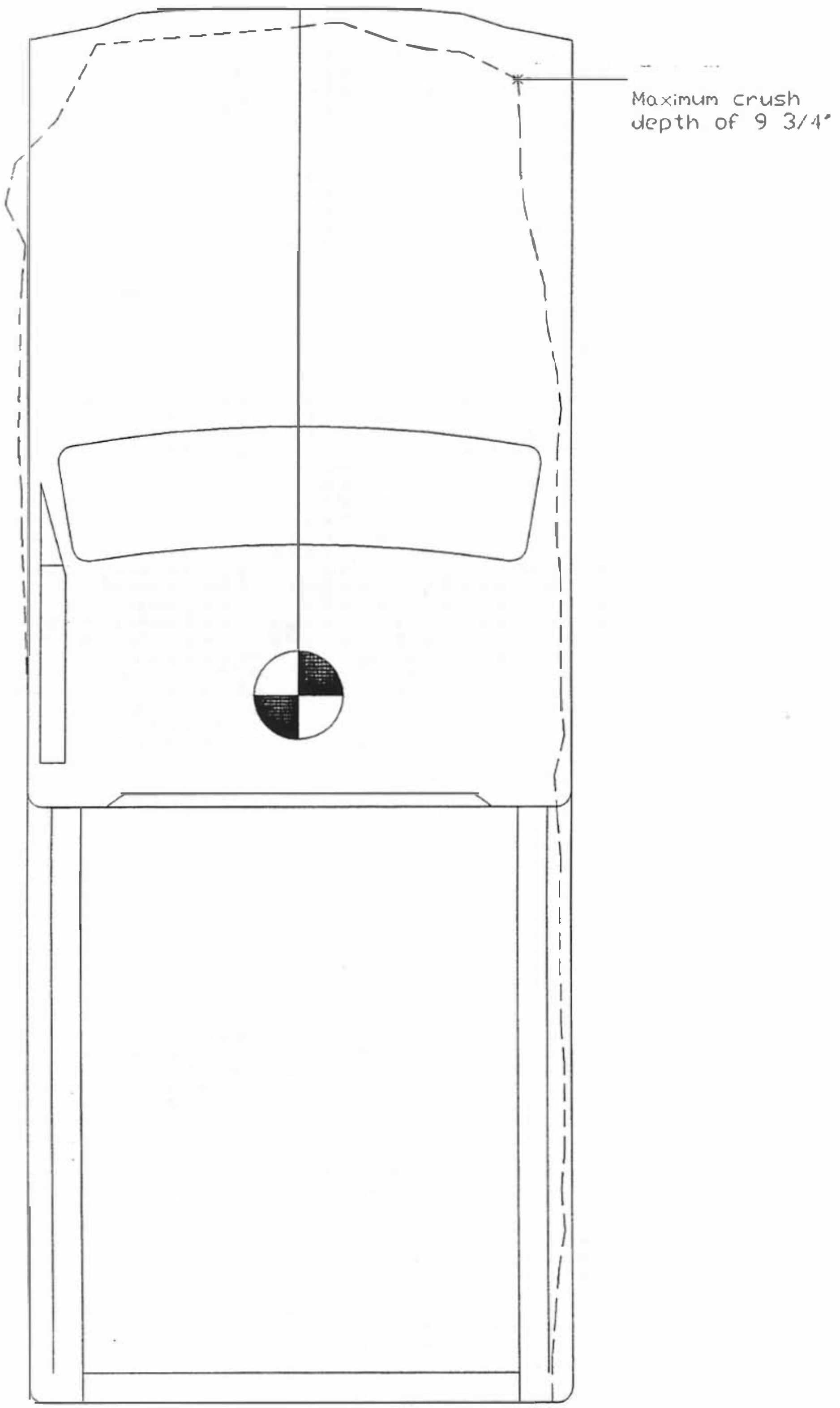


Figure 32. Vehicle Crush Measurements, Test GWMP-3.

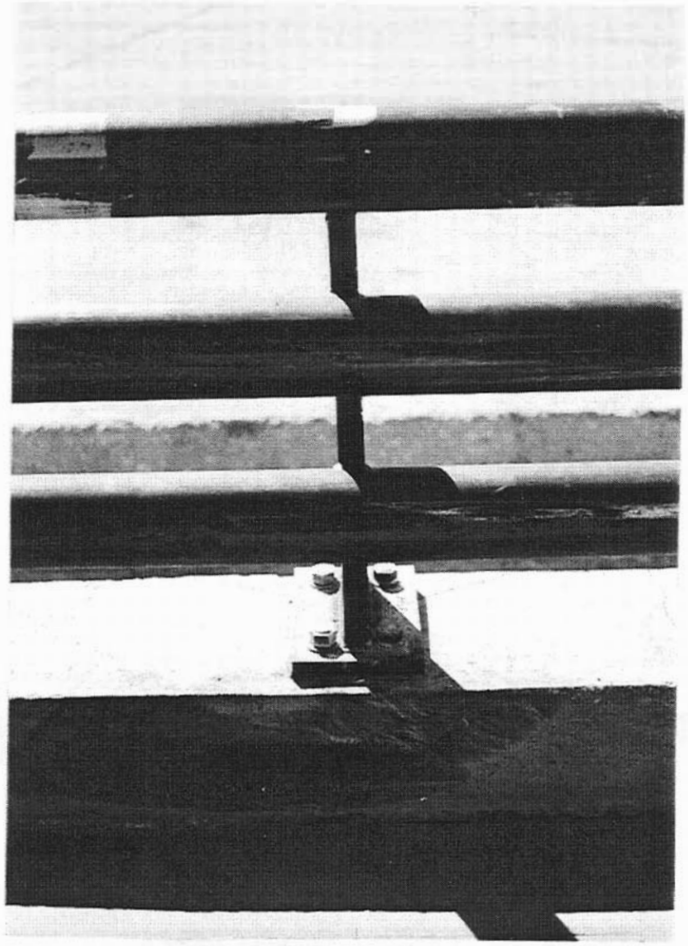


Figure 33. Bridge Rail Damage, Test GWMP-3.

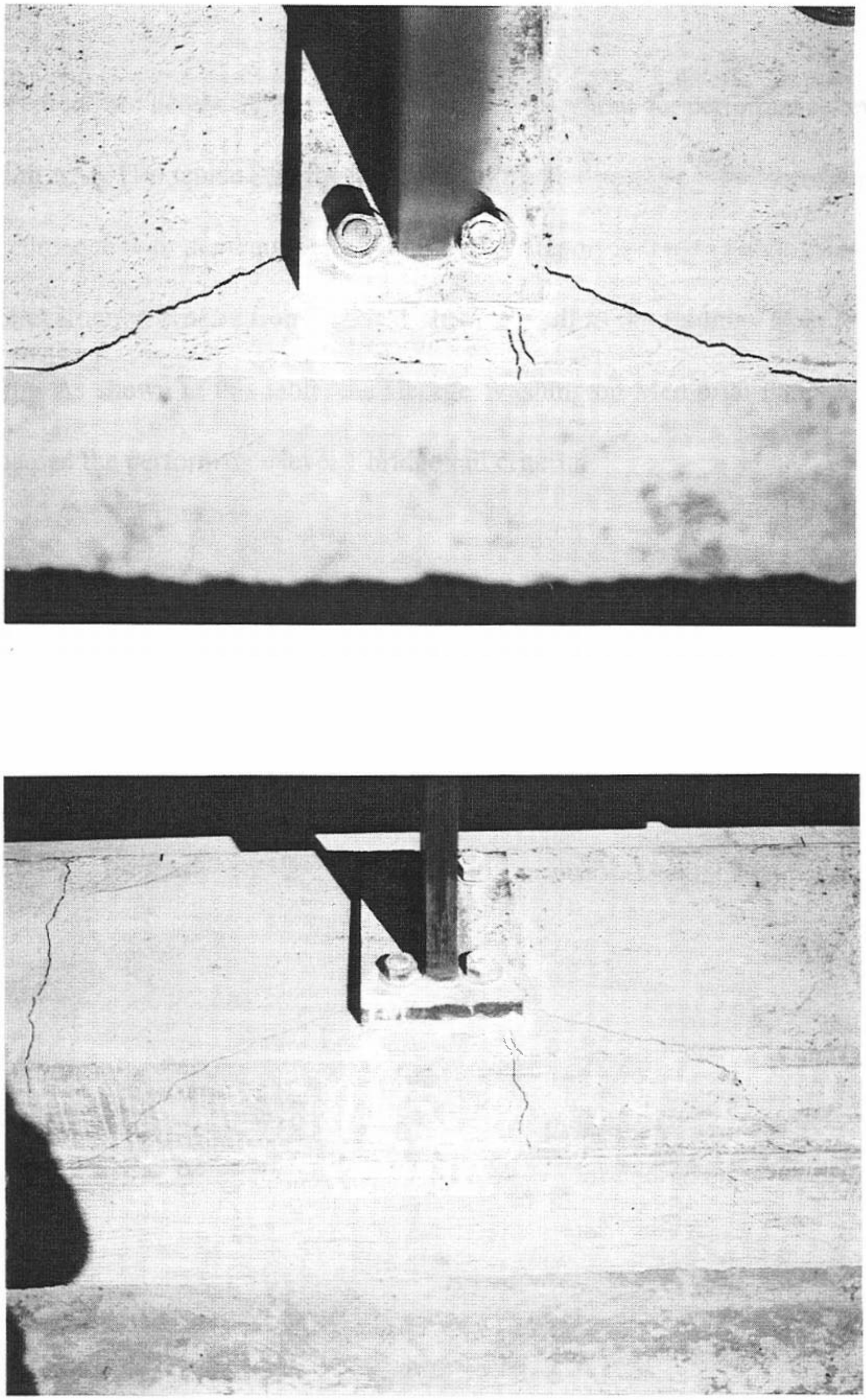


Figure 34. Curb Damage, Test GWMP-3.

5. CONCLUSIONS

The tests described herein were evaluated according to criteria for performance level 1 bridge rails presented in AASHTO Guide Specifications for Bridge Railings (3). They were conducted and reported in accordance with the requirements in NCHRP Report 230 (4). Table 1 summarizes all of the relevant evaluation criteria from AASHTO (3), as well as the findings from the three tests reported herein. As shown in this table, the George Washington Memorial Parkway bridge rail successfully passed the performance level 1 bridge rail criteria.

Table 1. Summary of Safety Performance Results.

<table>
<tr><th rowspan="2">Evaluation Criteria</th><th colspan="6">Results</th></tr>
<tr><th colspan="2">GWMP-1</th><th colspan="2">GWMP-2</th><th colspan="2">GWMP-3</th></tr>
<tr><td>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.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>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.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.e. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.</td><td colspan="2">U</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.d. The vehicle shall remain upright during and after collision.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>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.</td><td colspan="2">S</td><td colspan="2">S</td><td colspan="2">S</td></tr>
<tr><td>3.f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_r/V)/\sin\theta$.

μ — Assessment
0.0 - 0.25 — Good
0.26 - 0.35 — Fair
> 0.35 — Marginal</td><td colspan="2">M
(062)</td><td colspan="2">F
(0.30)</td><td colspan="2">G
(0.10)</td></tr>
<tr><td rowspan="6">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 — Lateral
30 — 25

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 — Lateral
15 — 15</td><td colspan="6">Occupant Impact Velocity (fps)</td></tr>
<tr><td>Long.</td><td>Lat.</td><td>Long.</td><td>Lat.</td><td>Long.</td><td>Lat.</td></tr>
<tr><td>S
(24.6)</td><td>S
(8.2)</td><td>S
(17.0)</td><td>S
(25.7)</td><td>S
(9.6)</td><td>S
(21.3)</td></tr>
<tr><td colspan="6">Occupant Ridedown Accelerations (g's)</td></tr>
<tr><td>Long.</td><td>Lat.</td><td>Long.</td><td>Lat.</td><td>Long.</td><td>Lat.</td></tr>
<tr><td>S
(12.0)</td><td>U
(22.4)</td><td>S
(5.20)</td><td>S
(9.6)</td><td>S
(2.0)</td><td>S
(5.0)</td></tr>
<tr><td rowspan="2">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.</td><td colspan="2">S
(3.8)</td><td colspan="2">S
(6.3 deg)</td><td colspan="2">S
(5.0 deg)</td></tr>
<tr><td colspan="2">S
(22 in. @ 40 ft.)</td><td colspan="2">U
(39 ft. @ 115 ft.)</td><td colspan="2">S
(3 ft. @ 40 ft.)</td></tr>
</table>

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

4. *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.

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

7. APPENDICES

APPENDIX A.

ACCELEROMETER DATA ANALYSIS, TEST GWMP-2

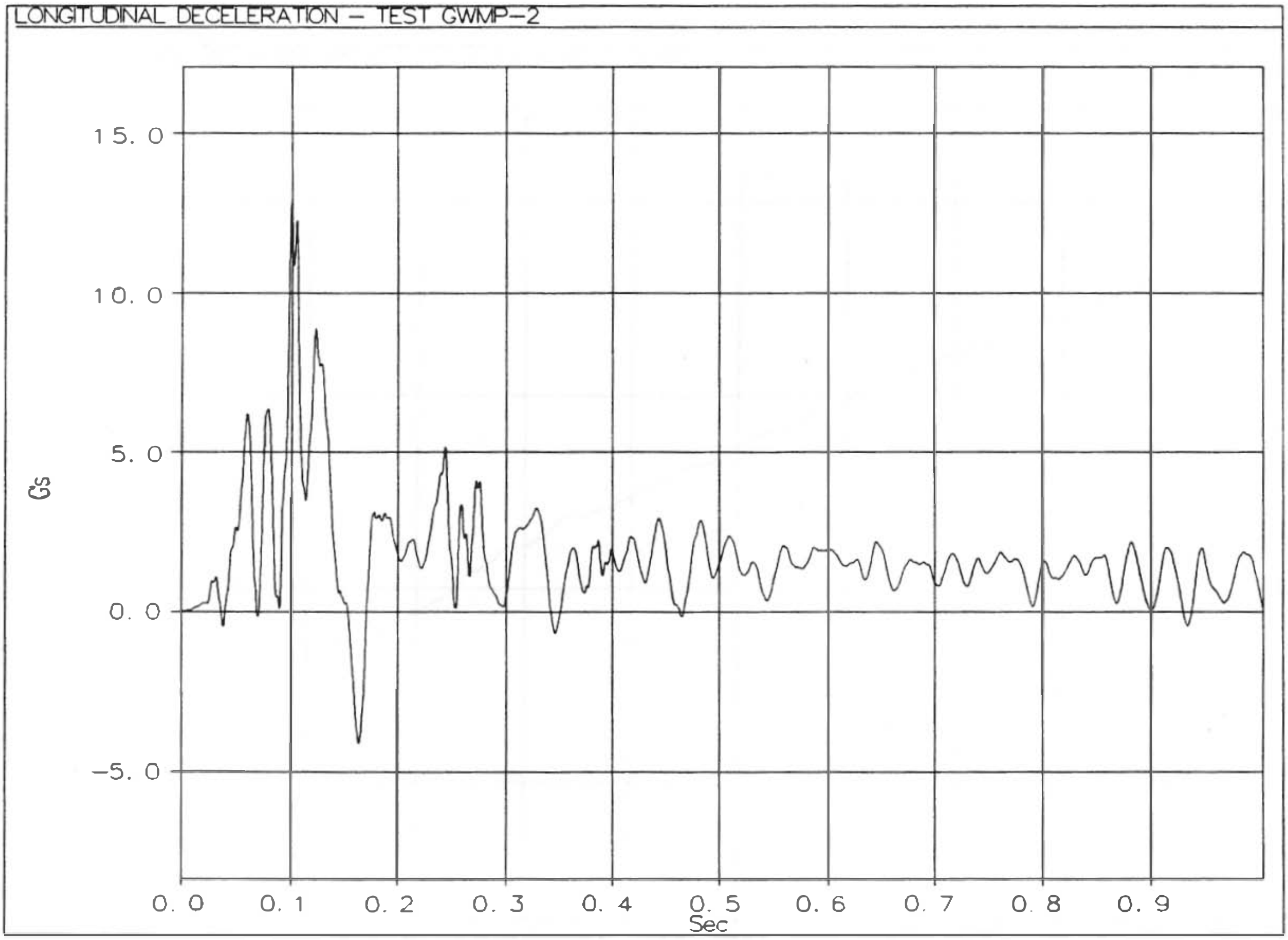


Figure A-1. Graph of Longitudinal Deceleration, Test GWMP-2.

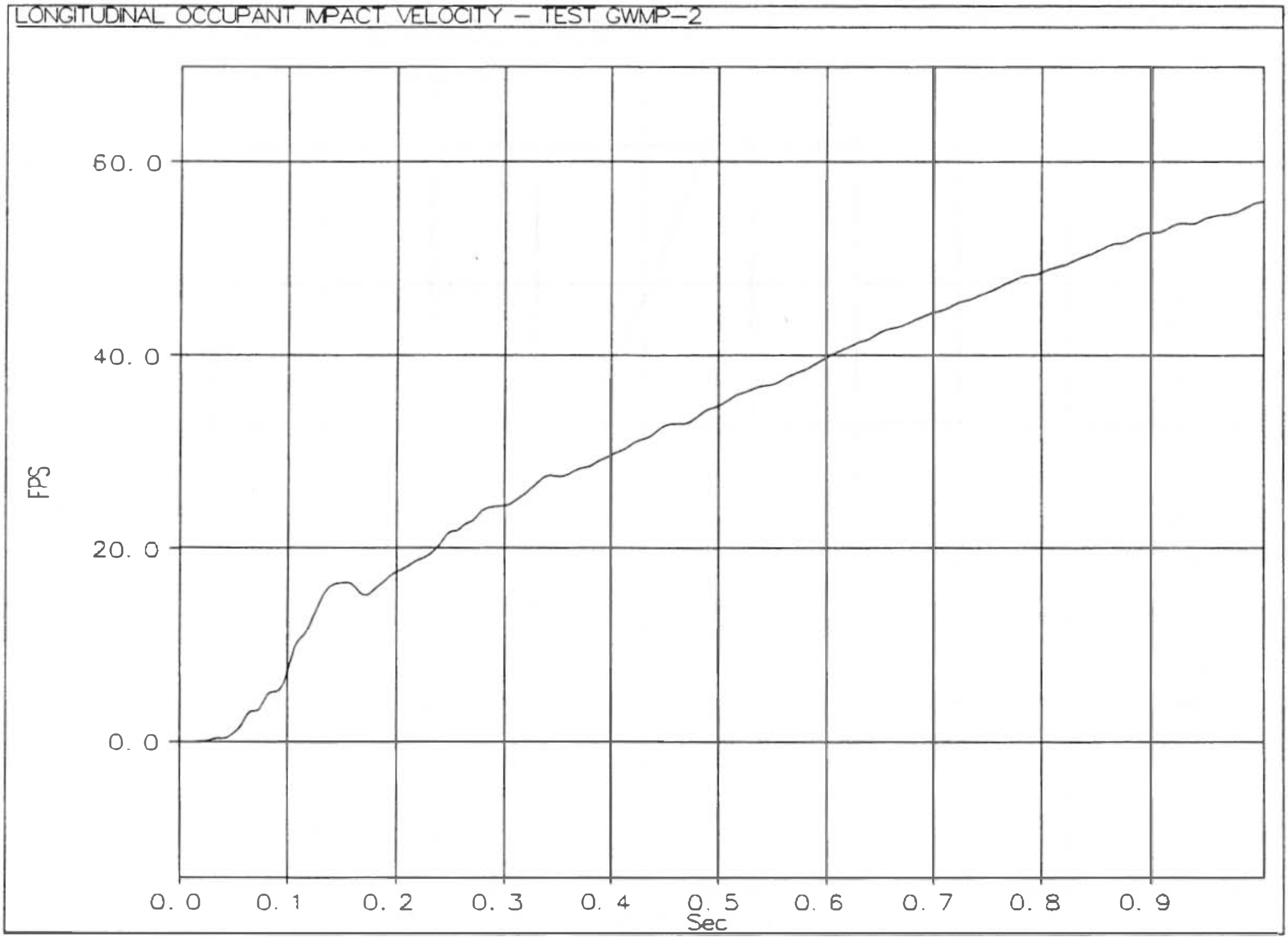


Figure A-2. Graph of Relative Longitudinal Occupant Velocity, Test GWMP-2.

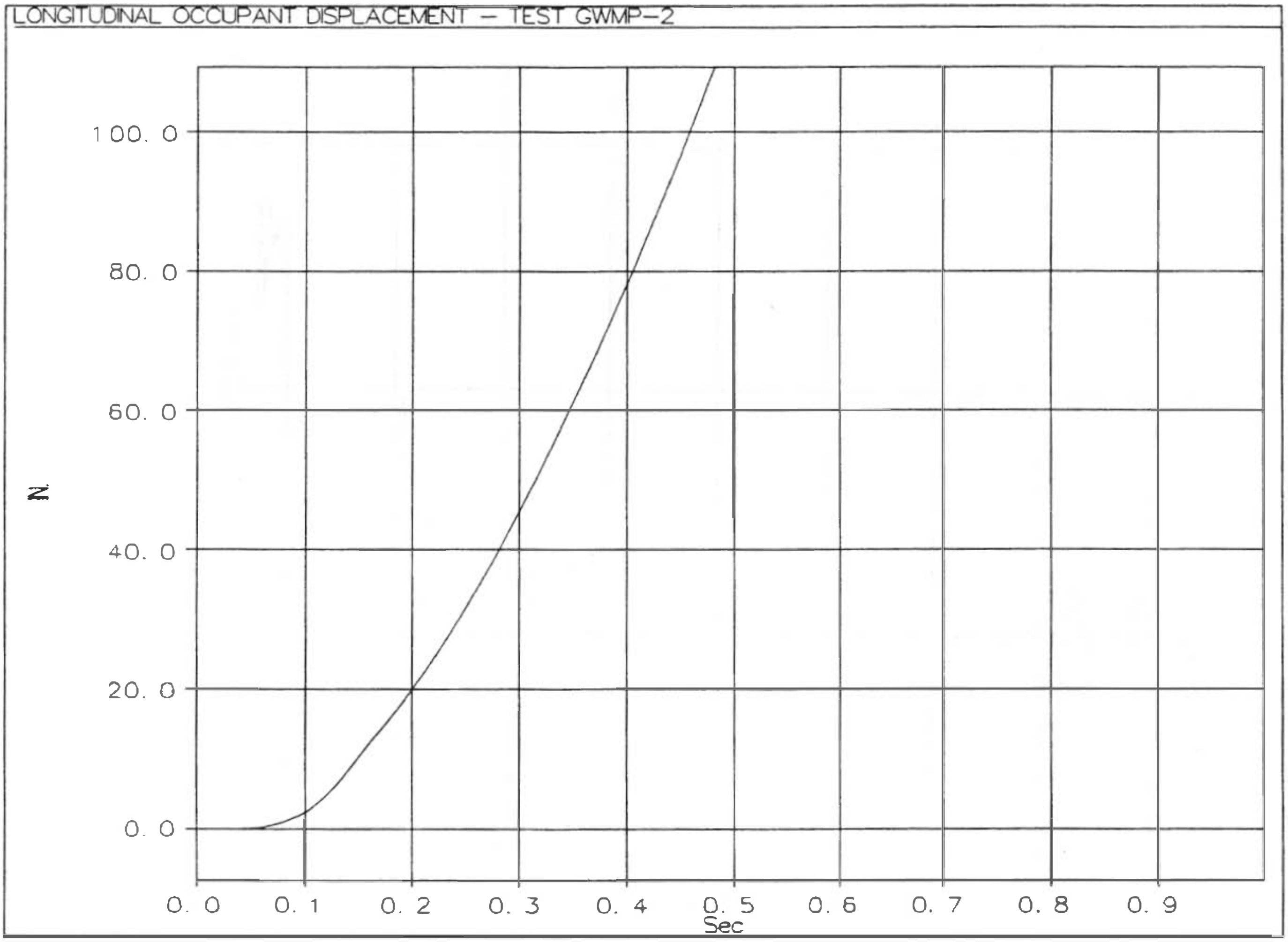


Figure A-3. Graph of Relative Longitudinal Occupant Displacement, Test GWMP-2.

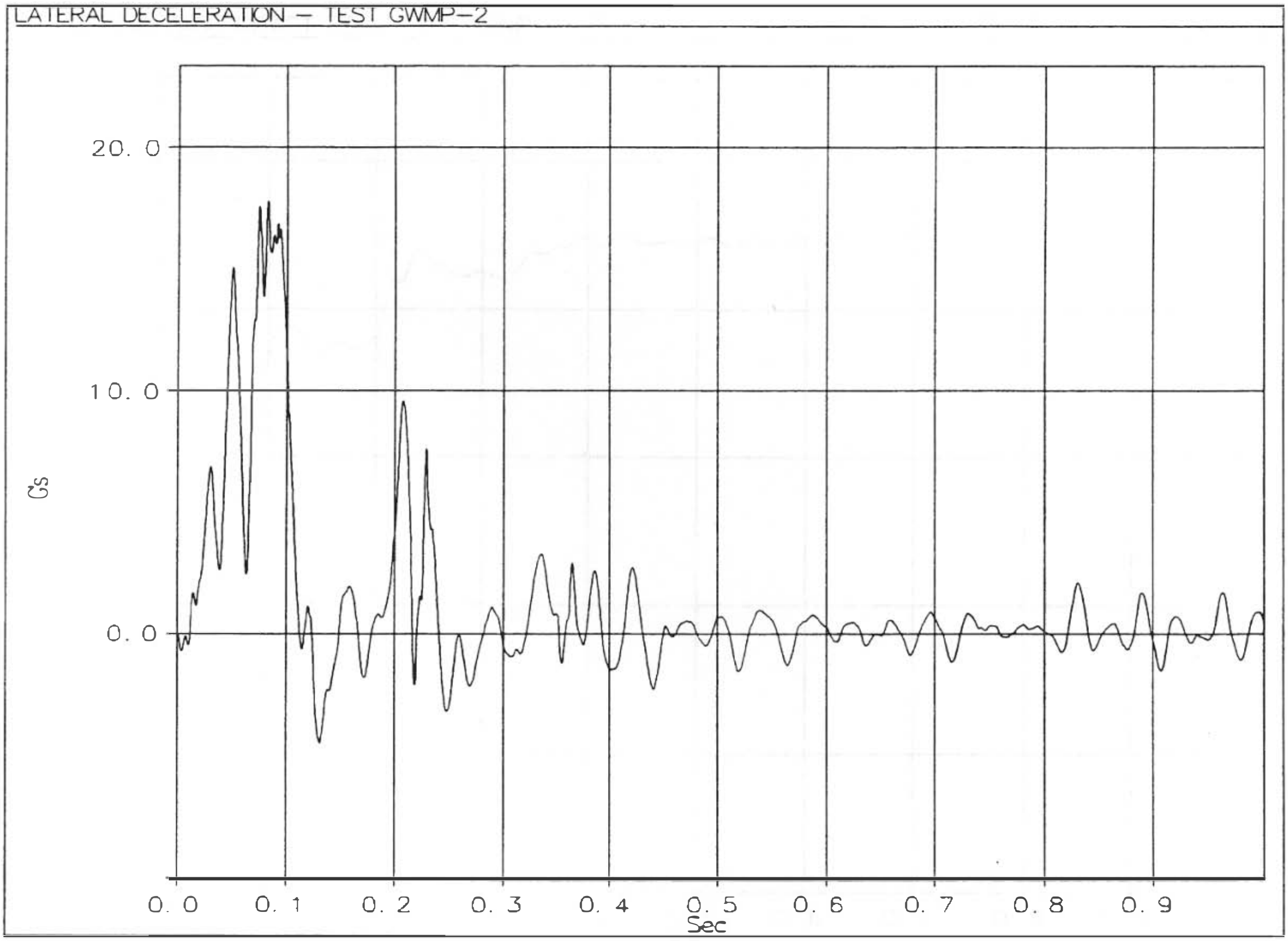


Figure A-4. Graph of Lateral Deceleration, Test GWMP-2.

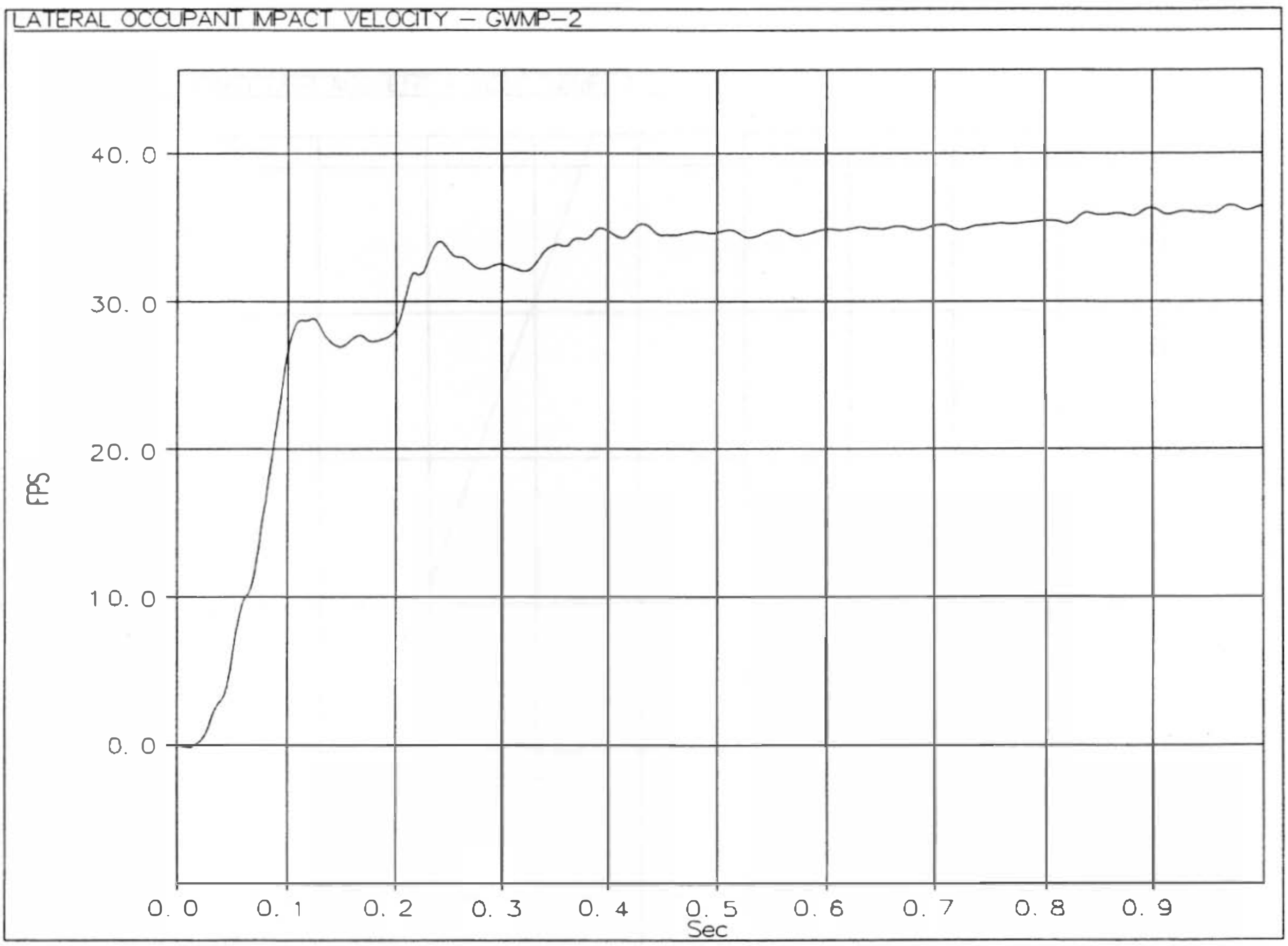


Figure A-5. Graph of Relative Lateral Occupant Velocity, Test GWMP-2.

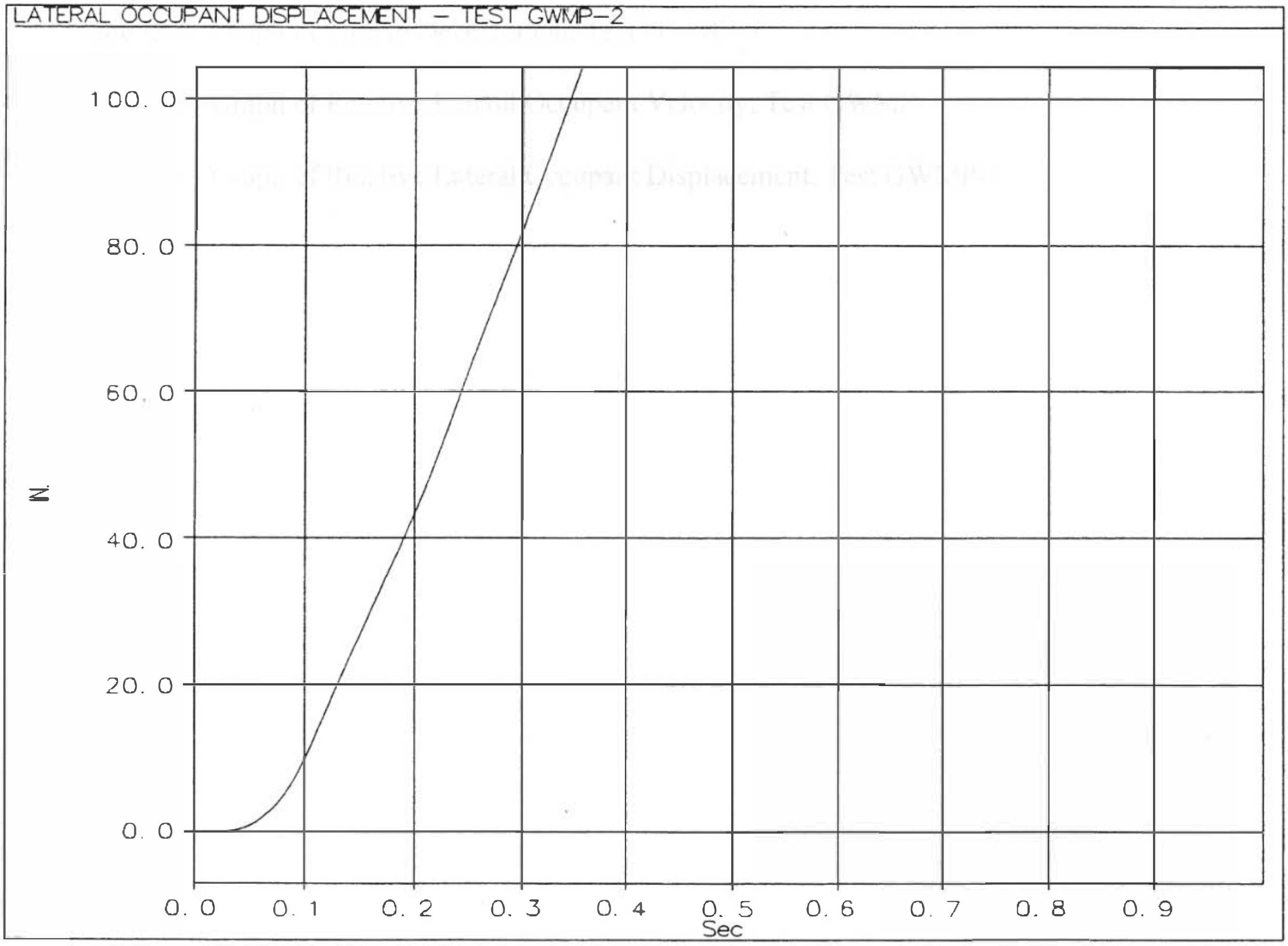


Figure A-6. Graph of Relative Lateral Occupant Displacement, Test GWMP-2.

APPENDIX B.

ACCELEROMETER DATA ANALYSIS, TEST GWMP-3

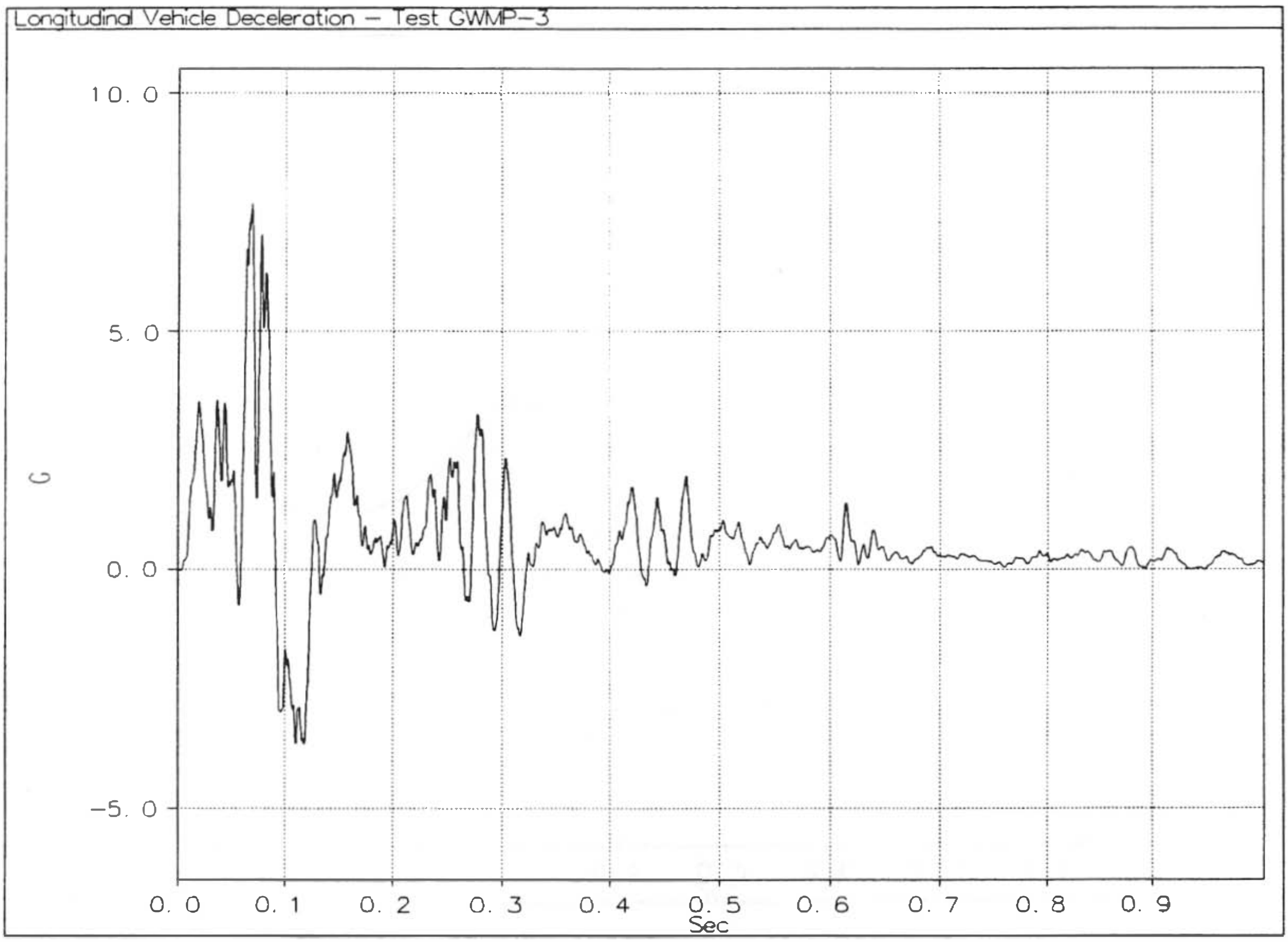


Figure B-1. Graph of Longitudinal Deceleration, Test GWMP-3.

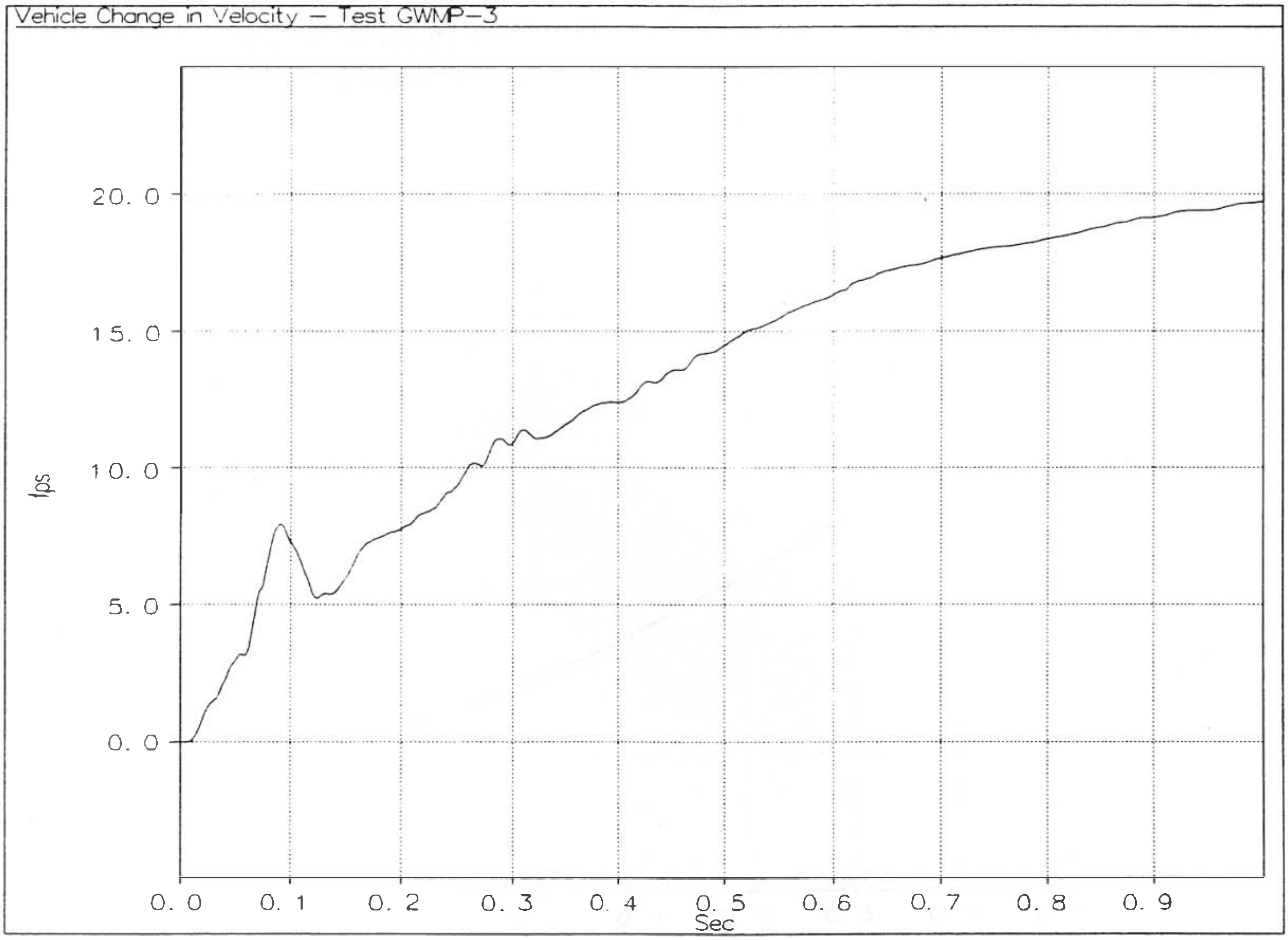


Figure B-2. Graph of Relative Longitudinal Occupant Velocity, Test GWMP-3.

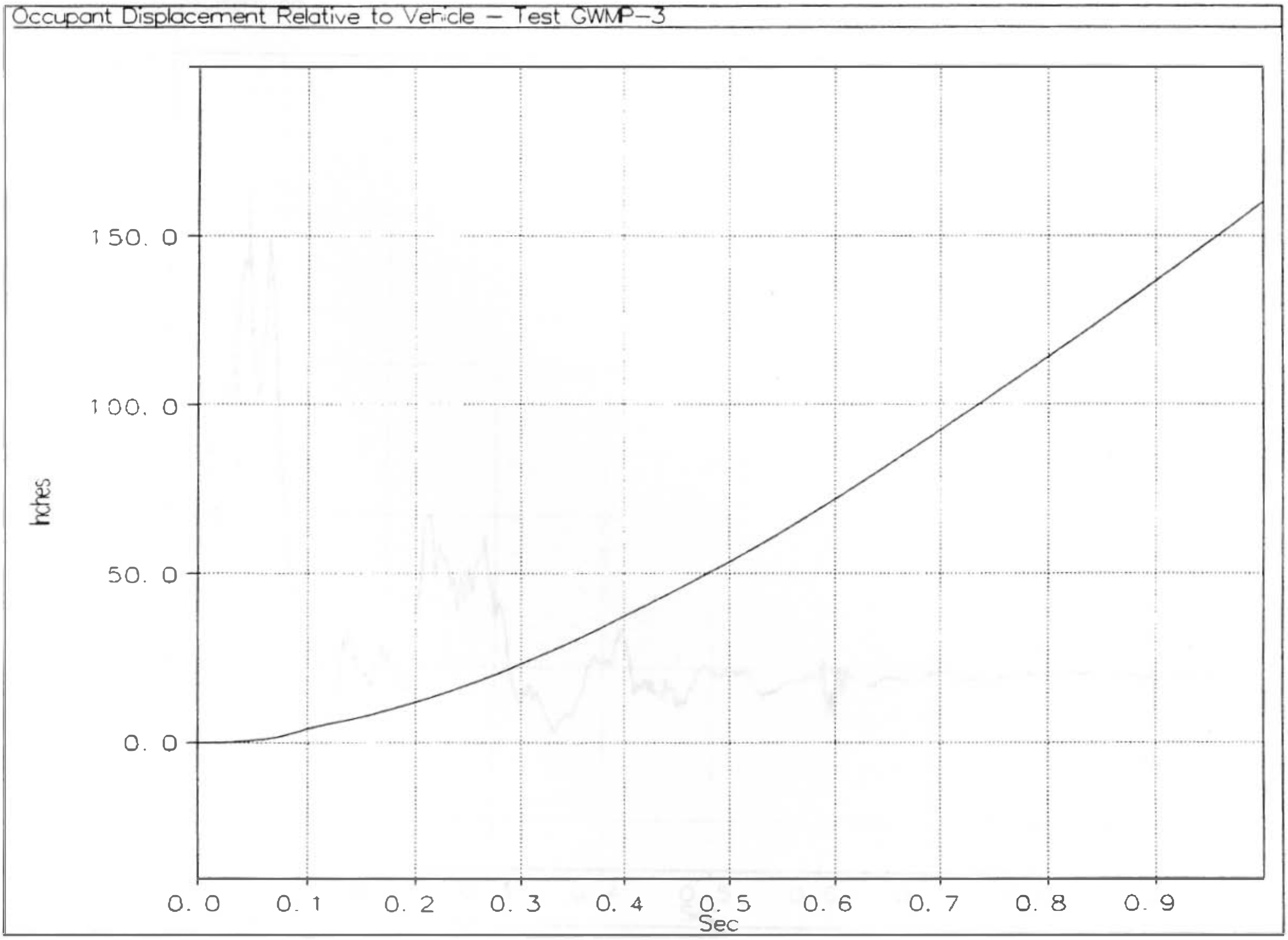


Figure B-3. Graph of Relative Longitudinal Occupant Displacement, Test GWMP-3.

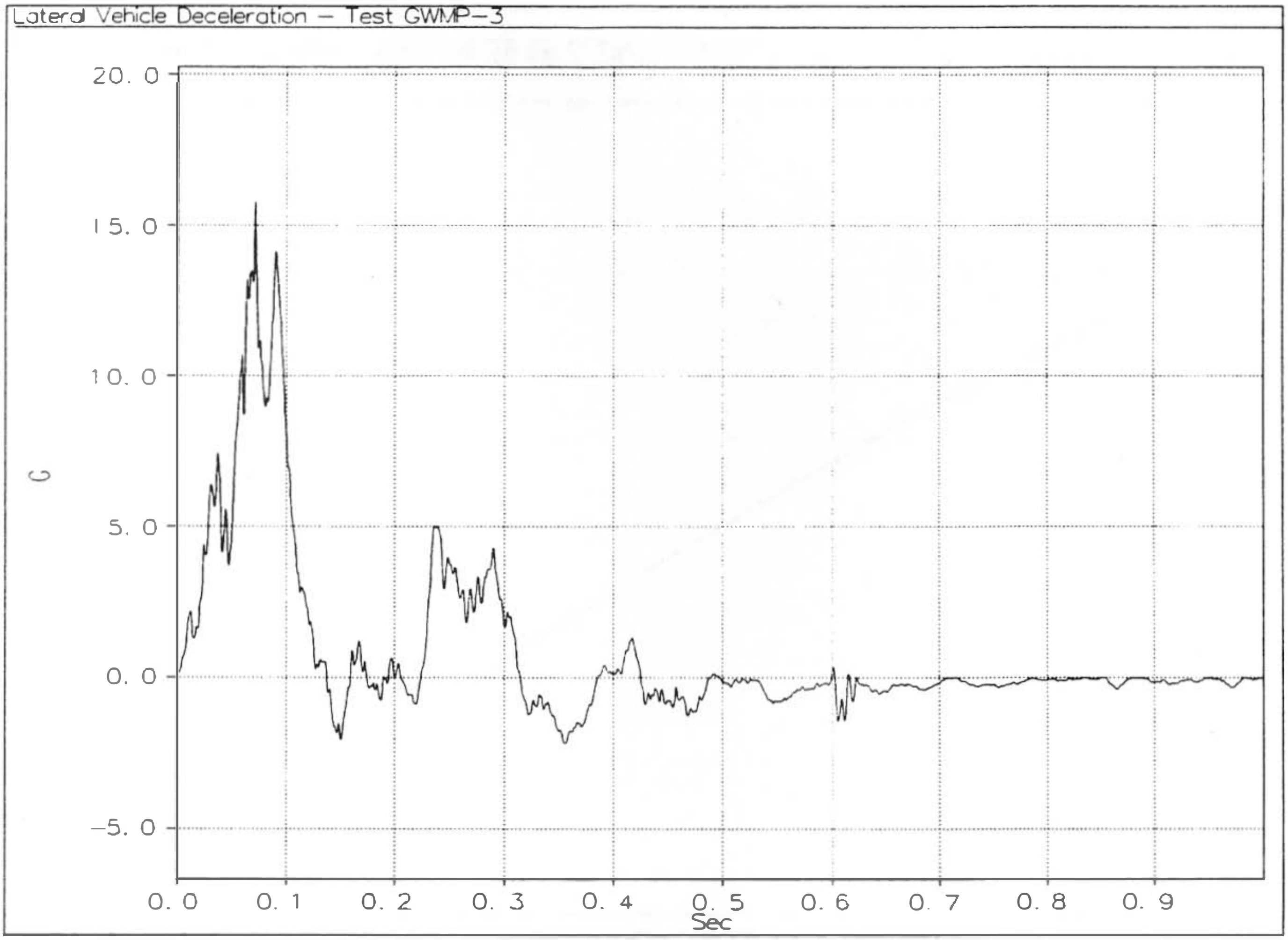


Figure B-4. Graph of Lateral Deceleration, Test GWMP-3.

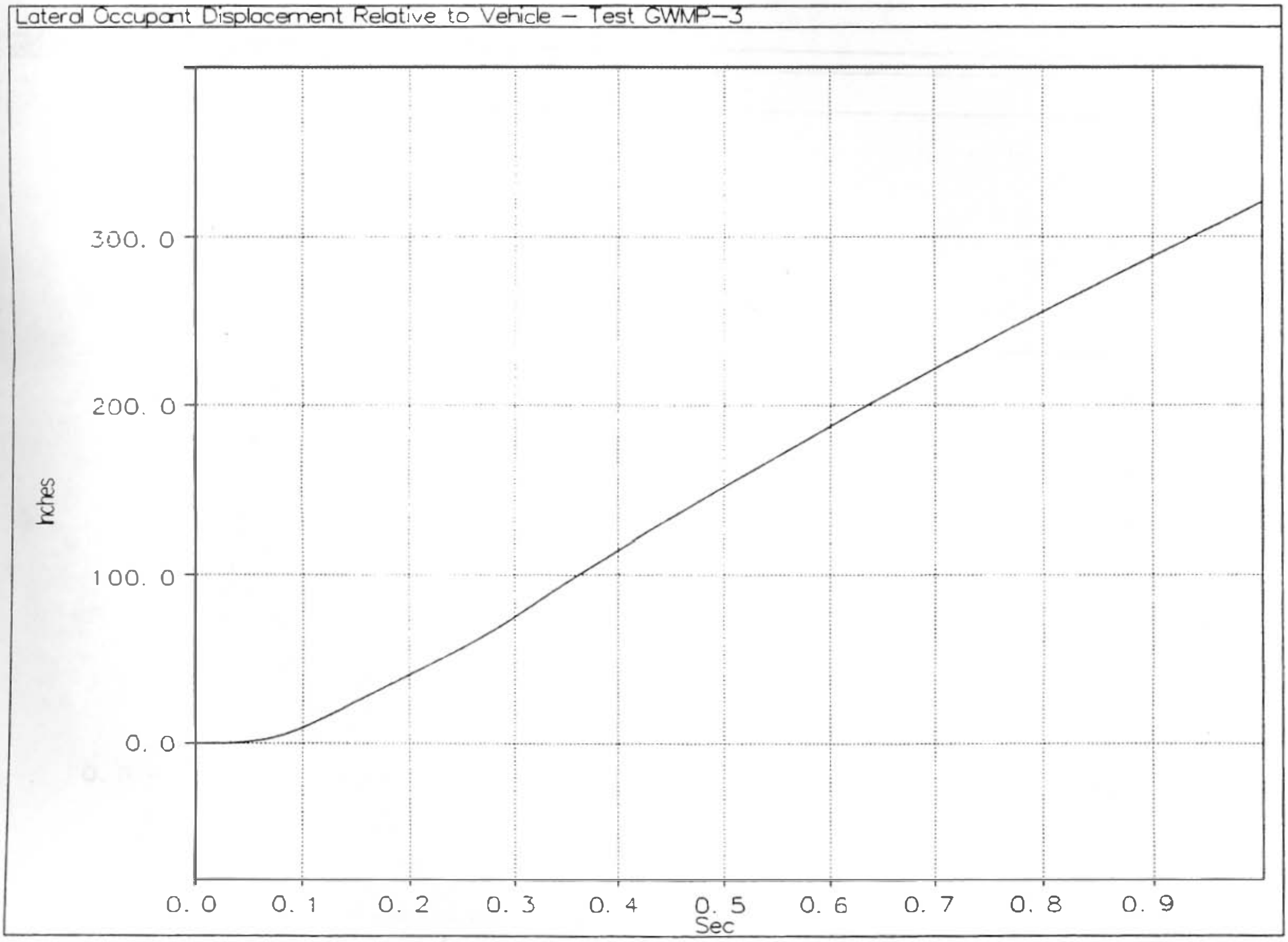


Figure B-5. Graph of Relative Lateral Occupant Velocity, Test GWMP-3.

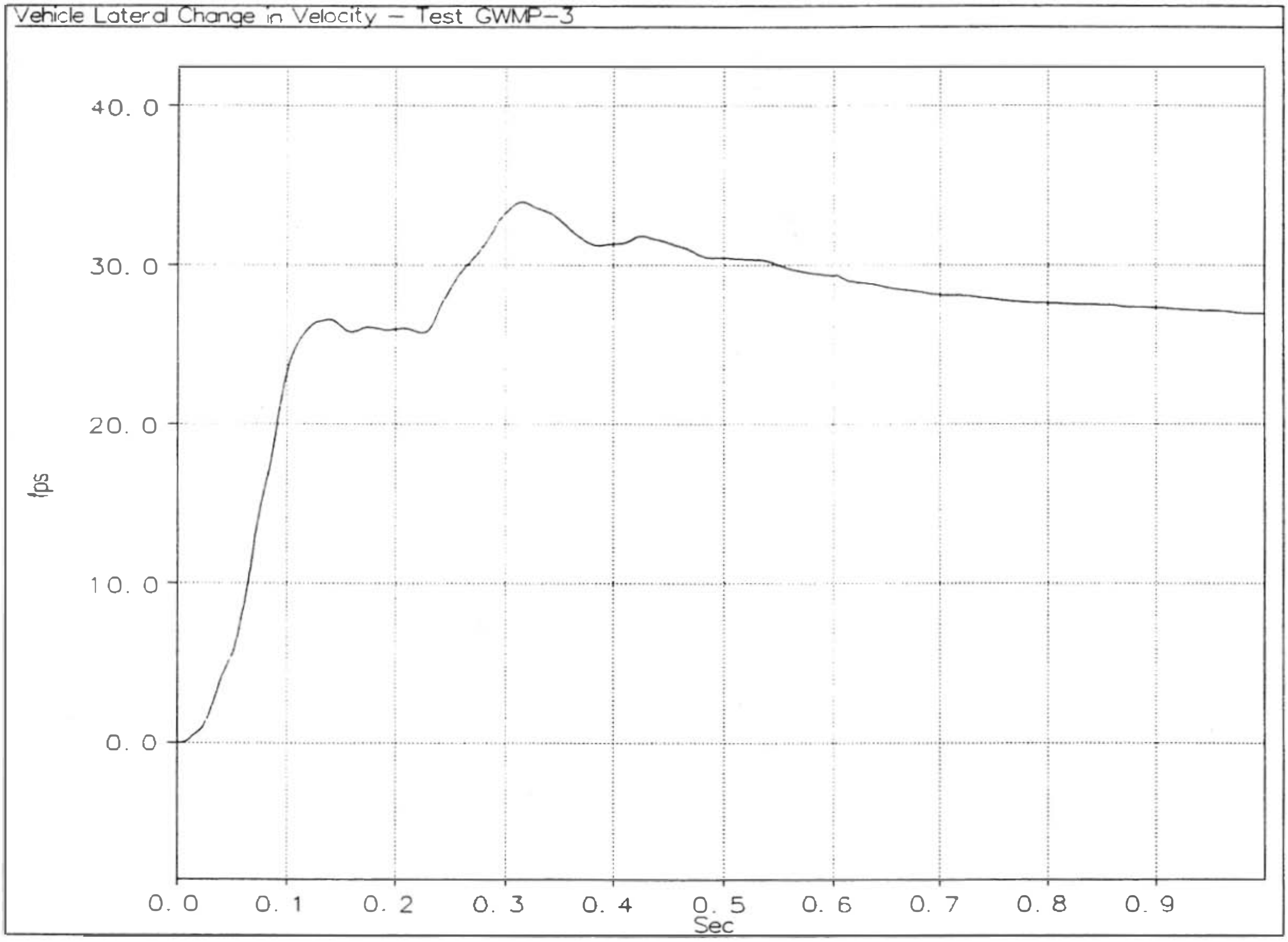


Figure B-6. Graph of Relative Lateral Occupant Displacement, Test GWMP-3.