Safety Performance Evaluation of a Nested W-Beam with Half-Post Spacing Over a Low-Fill Culvert

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DISCLAIMER STATEMENT

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I. INTRODUCTION

A. Problem Statement

Guardrails are often placed over box culverts to protect motorists from the hazard presented by cross-drainage culverts installed under highways. Unfortunately, the performance of these guardrails is seriously diminished when the box culvert is installed with less than 40 in. of fill material. Hirsch developed a design for alleviating this problem that utilized W6×9 steel posts bolted to the top of the box culvert (1). However, this design requires that the front face of the W-beam be placed 3 ft from the head wall of the culvert to provide space for the guardrail to deflect during impact. In many cases this design requires the culvert to be extended, thereby significantly increasing the cost of the structure, especially in rehabilitation projects where no other culvert work would be required.

An alternative design was therefore proposed by the Kansas Department of Transportation that would provide a stiffer barrier and thereby reduce the amount of deflection over the culvert. This design consisted of a nested W-beam supported by W6×9 steel posts spaced at 3 ft 1½ in. on center and bolted to the top slab of the concrete box culvert. The strengthened barrier was then placed adjacent to the culvert headwall.

B. Objective

The objective of this study was to determine if the revised design would provide adequate safety performance for full-size automobile impacts with the guardrail posts placed adjacent to the culvert headwall. If the safety evaluation of this test, conducted and evaluated according to NCHRP 230 (2), was favorable, considerable savings could be recognized since extending the concrete box culvert would no longer be necessary.

C. Test Installation

Photographs of the test installation are shown in Figure 1, with design details shown in Figure 2. The test installation consisted of 12-gauge W-beam guardrail spanning a 10-ft wide concrete box culvert. The top of the box culvert was located 9 in. below grade. The strength of the concrete in the box culvert was tested to be 5130 psi at the time of the safety evaluation. The W6×9 steel posts were spaced at 6 ft 3 in. on center except over and adjacent to the low fill culvert where the spacing was reduced to 3 ft 1½ in. The shortened posts located over the culvert were bolted to the top slab of the culvert as shown in Figure 2. The posts over the culvert were installed adjacent to the concrete headwall on the end of the box culvert. The remainder of the posts were installed by augering holes and backfilling while tamping around the post. An 18 ft 6 in. length of nested guardrail was centered over the culvert. Both ends of the 169 ft long installation were anchored with a standard Breakaway Cable Terminal (BCT).

FIGURE 1. Photographs of the nested W-beam with half-post spacing over a low-fill culvert

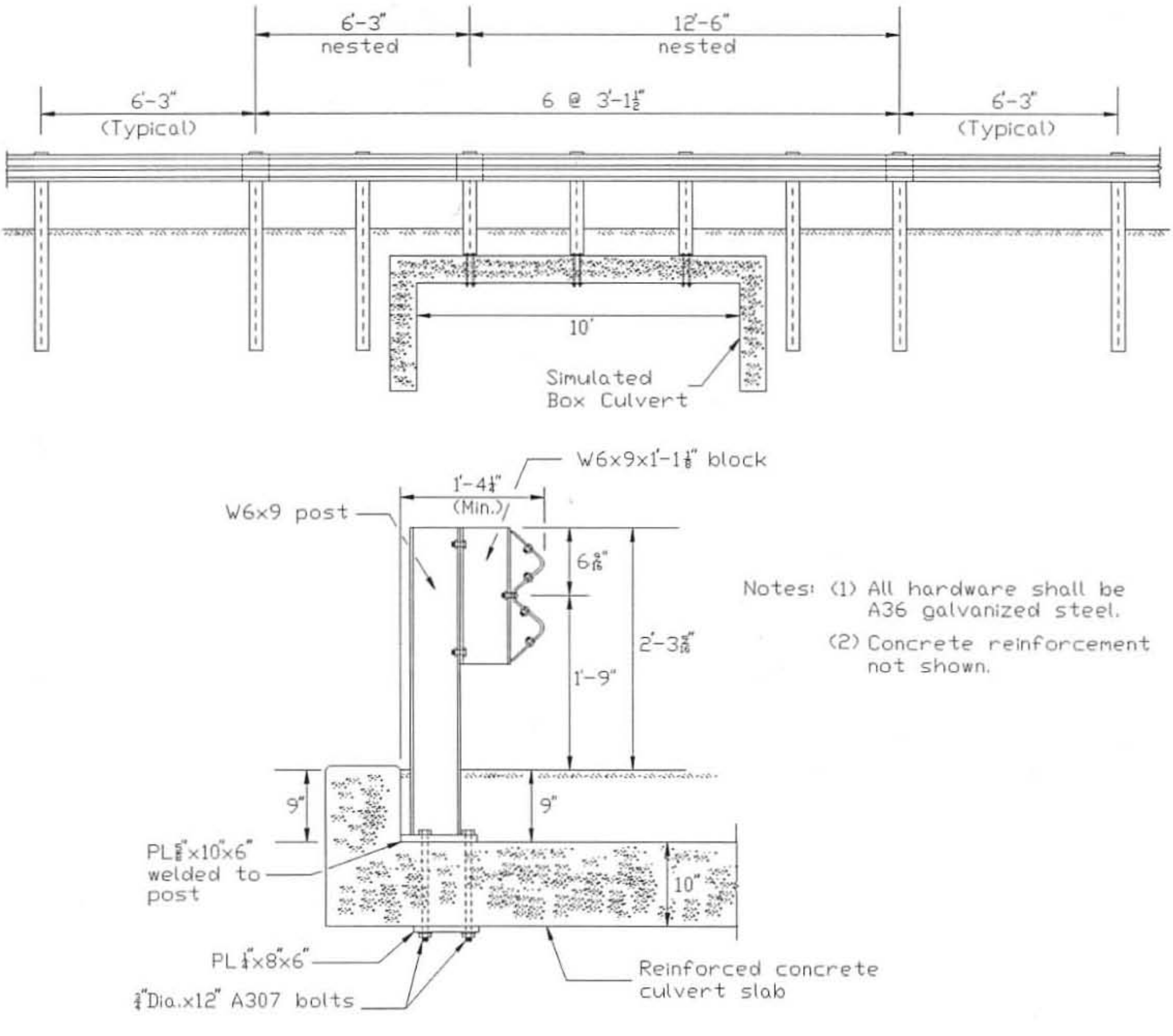


FIGURE 2. Details of the nested W-beam with half-post spacing over a low-fill culvert

II. TEST CONDITIONS

A. Test Vehicle

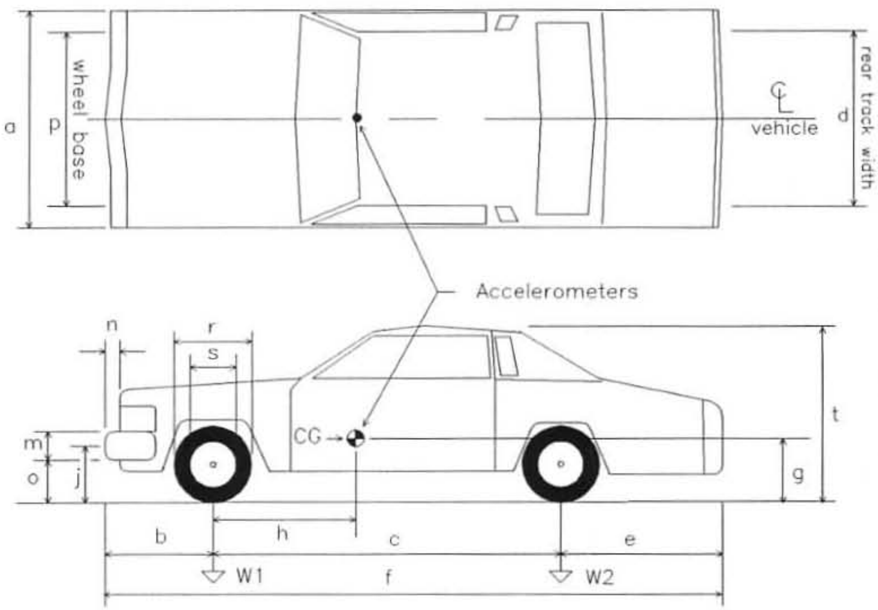
A 4500-lb 1985 Ford LTD, shown in Figure 3, was used as the test vehicle. Dimensions and axle weights of the test vehicle are shown in Figure 4. Black and white-checkered targets were placed on the vehicle for high-speed film analysis. Two targets were located on the center of gravity, one on the top and one on the driver's side of the test vehicle. Additional targets were located for reference so that they could be viewed from all cameras. The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero to ensure proper tracking of the vehicle along the guide cable. Two 5B flash bulbs, fired by a pressure tape switch on the front bumper, were mounted on the roof of the vehicle to establish the time of impact on the high-speed film.

FIGURE 3. Test Vehicle

Date: 10/2/92 Test No.: 36-1 Vehicle I.D.#: 1FABP43F9FZ109210

Make: Ford Model: LTD 4-door Year: 1985

Tire Size: P215-75R14 Odometer: 58015



Vehicle Geometry
Inches

a —	72	b —	38
c —	114	d —	62.25
e —	54	f —	206
g —	22.5	h —	47.5
j —	18	m —	7.5
n —	4	o —	14
p —	63	r —	26
s —	15.5	t —	55.5

Engine Type: V8

Engine Size: 5.8L

Transmission Type: Automatic

Weight – pounds	Curb	Test Inertial	Gross Static
W1	2165	2526	2526
W2	1535	1974	1974
Wtotal	3700	4500	4500

Damage prior to test: None

FIGURE 4. Test Vehicle Data Sheet

B. Data Acquisition Systems

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 a metal 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. Computer software "Computerscope" and "DSP" were used to digitize, analyze, and plot the accelerometer data.

2. High Speed Photography

Four high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec were used to film the crash tests. A Red Lake Locam with a 12.5 mm lens was placed above the test installation to provide a field of view perpendicular to the ground. A second Red Lake Locam with a 12.5-mm lens was located behind the rail. A Photec IV, with an 80-mm lens, was placed upstream from the impact point and had a field of view parallel to the guardrail. A second Photec IV, with a 55-mm lens, was placed on the traffic side of the guardrail and had a field of view perpendicular to the barrier. A schematic of the camera locations for the test is shown in Figure 5. A white-colored backboard with a 2-ft by 2-ft grid was placed behind the rail in view of the overhead camera. This backboard 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.

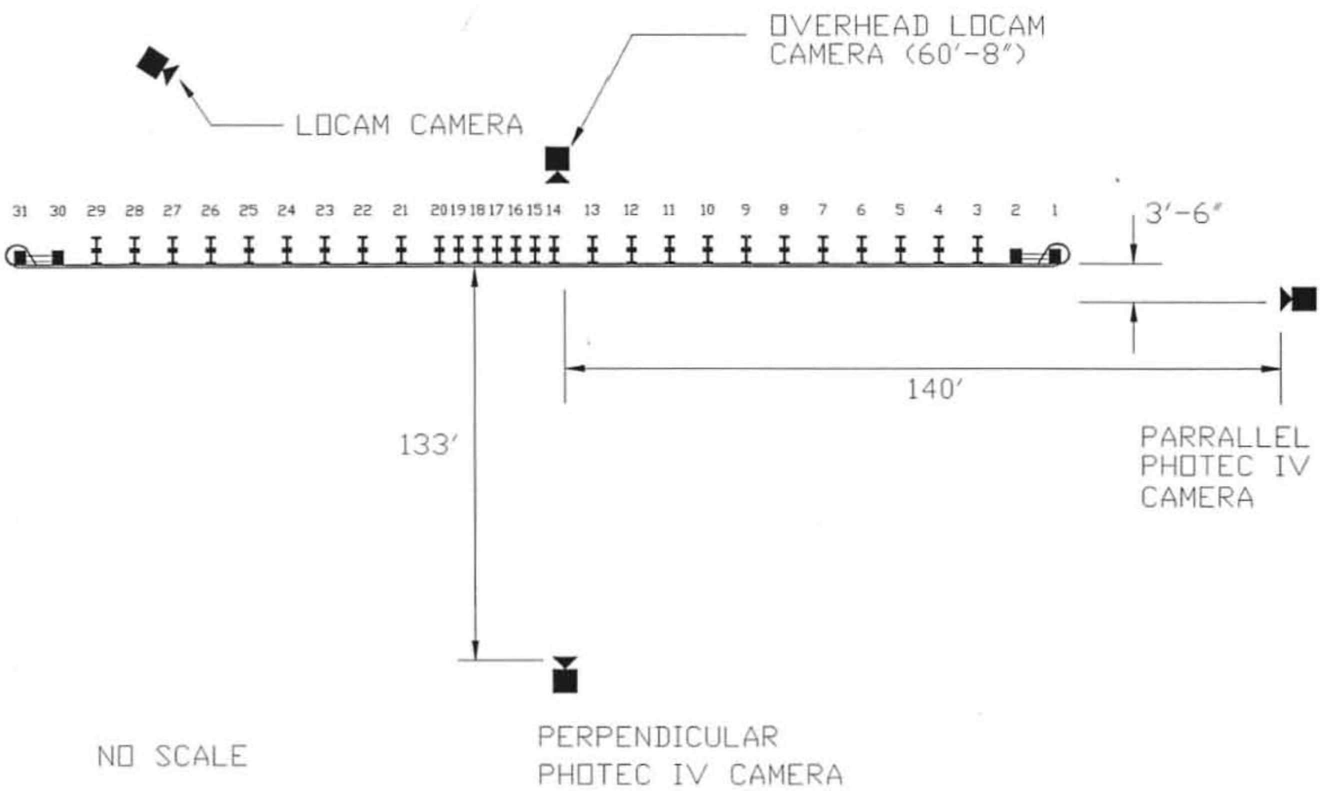


FIGURE 5. Schematic of camera locations

3. Speed Trap

Seven pressure tape switches spaced at 5-ft intervals were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal 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.

III. TEST RESULTS

A. Test 36-1 (4500 lbs, 61.0 mph, 28.2 deg)

The 1985 Ford LTD was directed into the W-beam guardrail system 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 and angle of the vehicle at impact were 61.0 mph and 28.2 degrees, respectively. The impact point, shown in Figure 6, was located 10 ft 9½ in. upstream from the center of the culvert. A summary of the test and sequential photographs are shown in Figure 7. Additional sequential photographs are shown in Figures 8 and 9.

Upon impact with the W-beam guardrail, the right front corner of the vehicle began to crush inward as the rail deflected. The right-front wheel then contacted Post No. 16 and was separated from the vehicle. The detached wheel then went under the rail and came to rest under the culvert. As the vehicle progressed along the rail, the first two posts bolted to the culvert (Post Nos. 16 and 17) were separated from the rail and bent over as shown in Figure 10. The test vehicle became parallel to the guardrail 202 ms after impact with a speed of 35.6 mph.

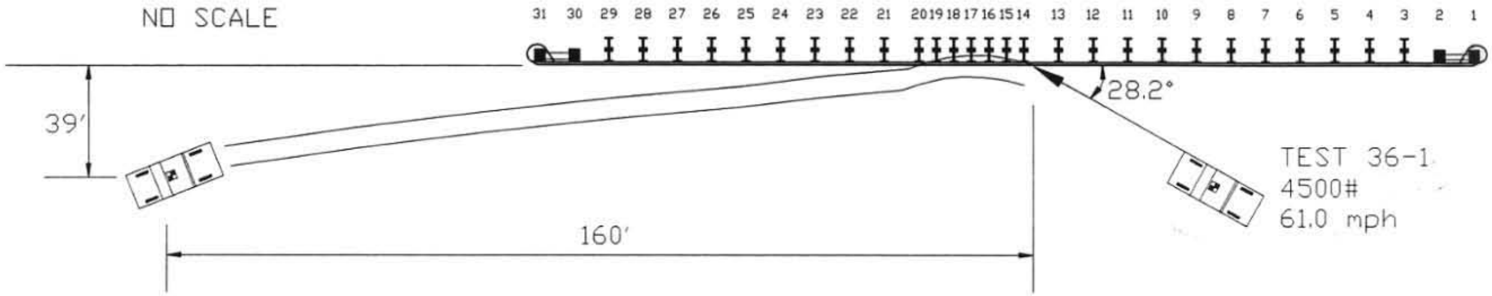
The vehicle exited the rail at an angle and speed of 7.7 degrees and 30.6 mph, respectively, 350 ms after impact. After exiting the rail the vehicle continued to travel downstream and to the left, coming to rest 160 ft downstream from impact and 39 ft to the left of a line parallel to the railing face. This vehicle trajectory is shown in Figures 7 and 10.

Damage to the W-beam system is shown in Figure 11. A maximum permanent set deflection of 18⅝ in. was measured at Post No. 16. Additional measurements of permanent set deflections of the guardrail are presented in Figure 12. The concrete box culvert was not damaged.

The test vehicle damage, shown in Figure 13, was extensive along the entire passenger side. The normalized longitudinal and lateral occupant impact velocities as determined from accelerometer data were 27.9 fps and 13.5 fps, respectively. The highest 10-ms average occupant ridedown decelerations were 11.3 g's (longitudinal) and 18.7 g's (lateral). The vehicle change in speed of 30.4 mph was greater than the value of 15 mph required by NCHRP 230 (2). However, many systems which have been approved for use by FHWA have been unable to pass this criteria (5,6), and the update to NCHRP Report 230 (4) does not contain this requirement. Accelerometer traces from this test are shown in Appendix A.

FIGURE 6. Vehicle Impact Location

Impact | 110 msec | 160 msec | 210 msec | 310 msec



Test Number	36-1
Date	10/27/92
Installation	Nested W-beam with half-post spacing over a low-fill culvert
Installation Length	169 ft
Post	
Size	W6×9
Length	6 ft
Guardrail	
Material	12 gauge W-beam (Nested over Culvert)
Post Spacing	
Over and adjacent to culvert	3 ft 1½ in.
Remaining spaces	6 ft 3 in.
End Treatments	Breakaway Cable Terminal
Test Vehicle	1985 Ford LTD
Test Inertial Weight	4500 lbs
Gross Static Weight	4500 lbs

Impact Speed	61.0 mph
Impact Angle	28.2 deg
Exit Speed	30.6 mph
Exit Angle	7.7 deg
Vehicle Change in Speed	30.4 mph
Normalized Occupant Impact Velocity	
Longitudinal	27.9 fps
Lateral	13.5 fps
Occupant Ridedown Deceleration	
Longitudinal	11.3 g's
Lateral	18.7 g's
Vehicle Damage	
TAD	1-RFQ-5, 1-RD-6
VDI	01RDES2
Maximum Permanent Set Deflection	18 ⅝ in. @ Post No. 16

FIGURE 7. Test 36-1 Summary

Impact

30 msec

60 msec

110 msec

160 msec

210 msec

310 msec

510 msec

FIGURE 8. Upstream Sequential Photographs

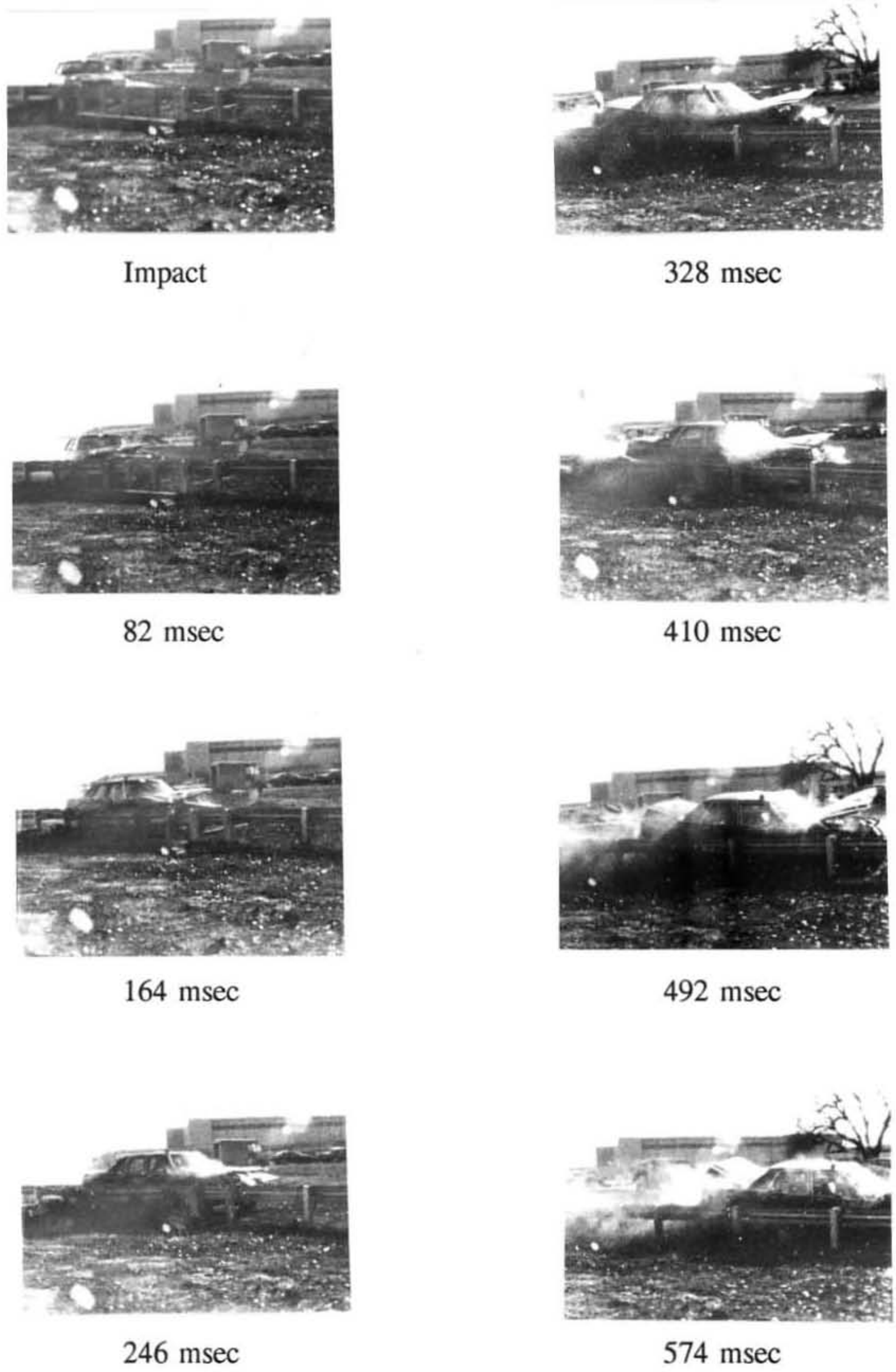


FIGURE 9. Sequential Photographs from behind rail

FIGURE 10. Guardrail Damage

FIGURE 11. Vehicle Trajectory

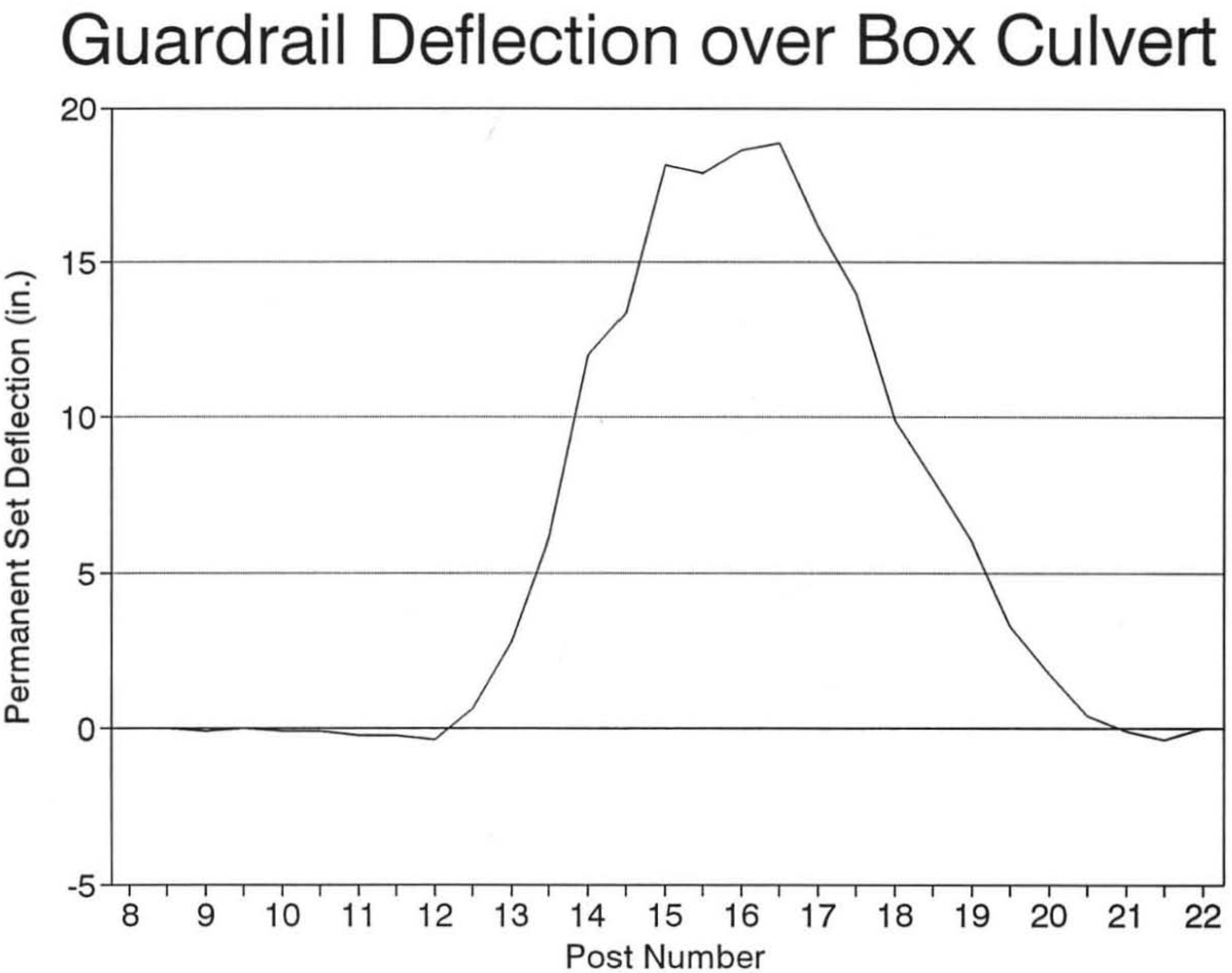


FIGURE 12. Permanent set rail deflections

FIGURE 13. Vehicle Damage

IV. CONCLUSIONS

NCHRP Report 230 (2) provides specific criteria for evaluating the performance of longitudinal barriers. Table 1 summarizes all of the relevant evaluation criteria from this report, as well as the findings from the test reported herein. This system met all of the evaluation criteria except for those referring to vehicle trajectory. It has been noted that many systems currently approved by the FHWA do not meet this requirement and that the update to NCHRP 230 (4) does not require that this criteria be met. Therefore, it was found that the safety performance of the nested W-beam with half-post spacing over a low-fill culvert was satisfactory.

Table 1. Safety Performance Results

Structural Adequacy	A. The test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	S
	D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S
Occupant Risk	E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	S
Vehicle Trajectory	H. After collision, vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent lanes.	U
	I. In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of the test impact angle, both measured at time of vehicle loss of contact with test device.	U

S - Satisfactory
M - Marginal
U - Unsatisfactory

V. REFERENCES

1. *Use of Guardrail on Low Fill Bridge Length Culverts*, T.J. Hirsch and D. Beggs, Texas Transportation Institute, Texas A&M University, Paper No. 870265, 67th Annual Meeting of the Transportation Research Board, Washington, D.C., January 1988.

2. *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.

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

4 *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, Phase 2 - Final Report, Texas Transportation Institute, The Texas A&M University System, College Station, TX, August 1992.

5. *Development of Guardrail to Bridge Rail Transition*, Bligh, R.P., Sicking, D.L., Ross, H.E., Publication No. FHWA/TX-87/461-1F, Texas Transportation Institute, Texas A&M University, College Station Texas, June 1988.

6. *Guardrail-Bridge Rail Transition Designs*, Bronstad, M.E., Calcote, L.R., Ray, M.H., Mayer, J.B., Publication No. FHWA/RD-86/178, Southwest Research Institute, San Antonio, Texas, April 1988.

APPENDIX A.

ACCELEROMETER TRACES

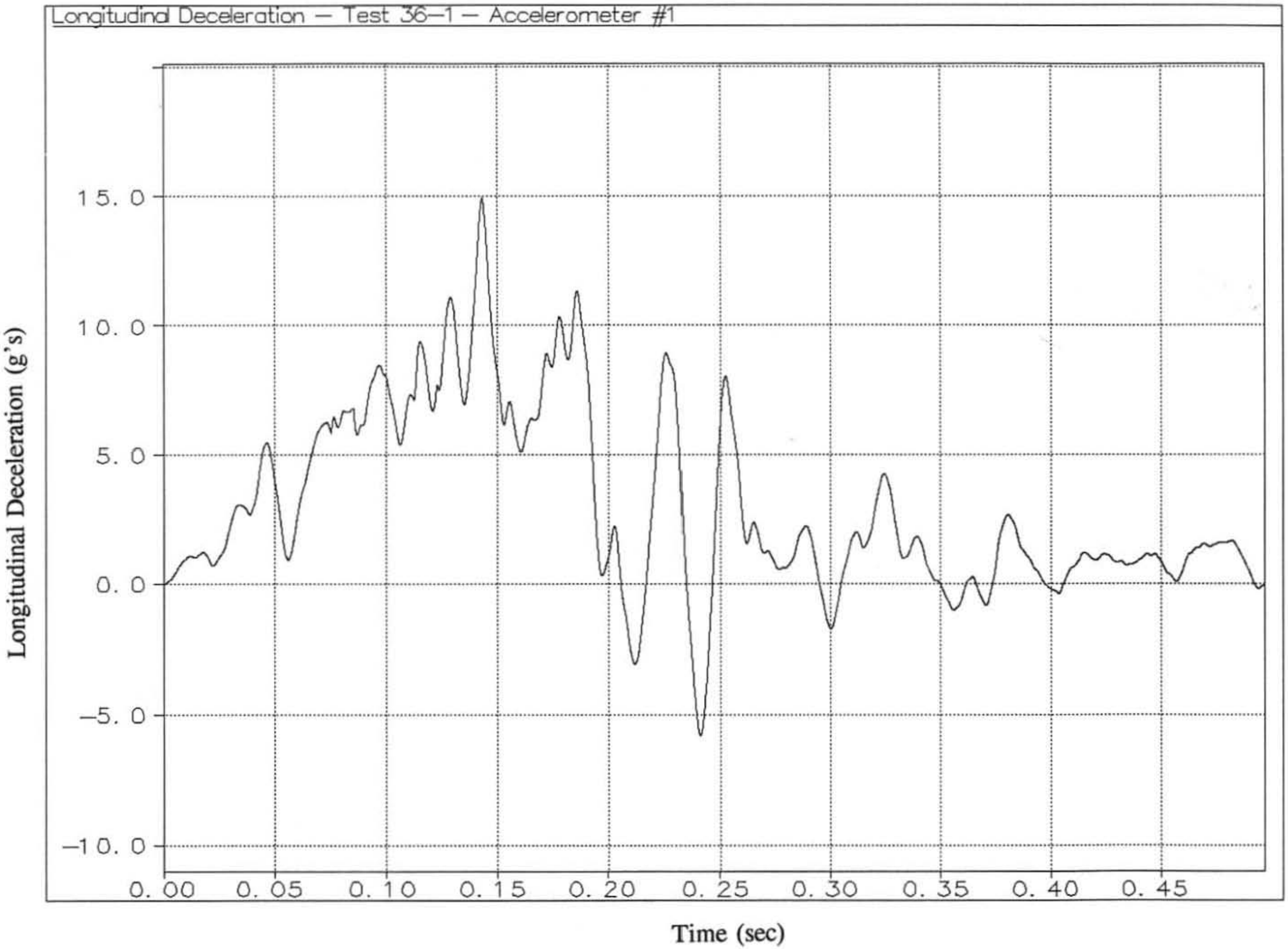


Figure A-1. Graph of Longitudinal Deceleration, Test 36-1

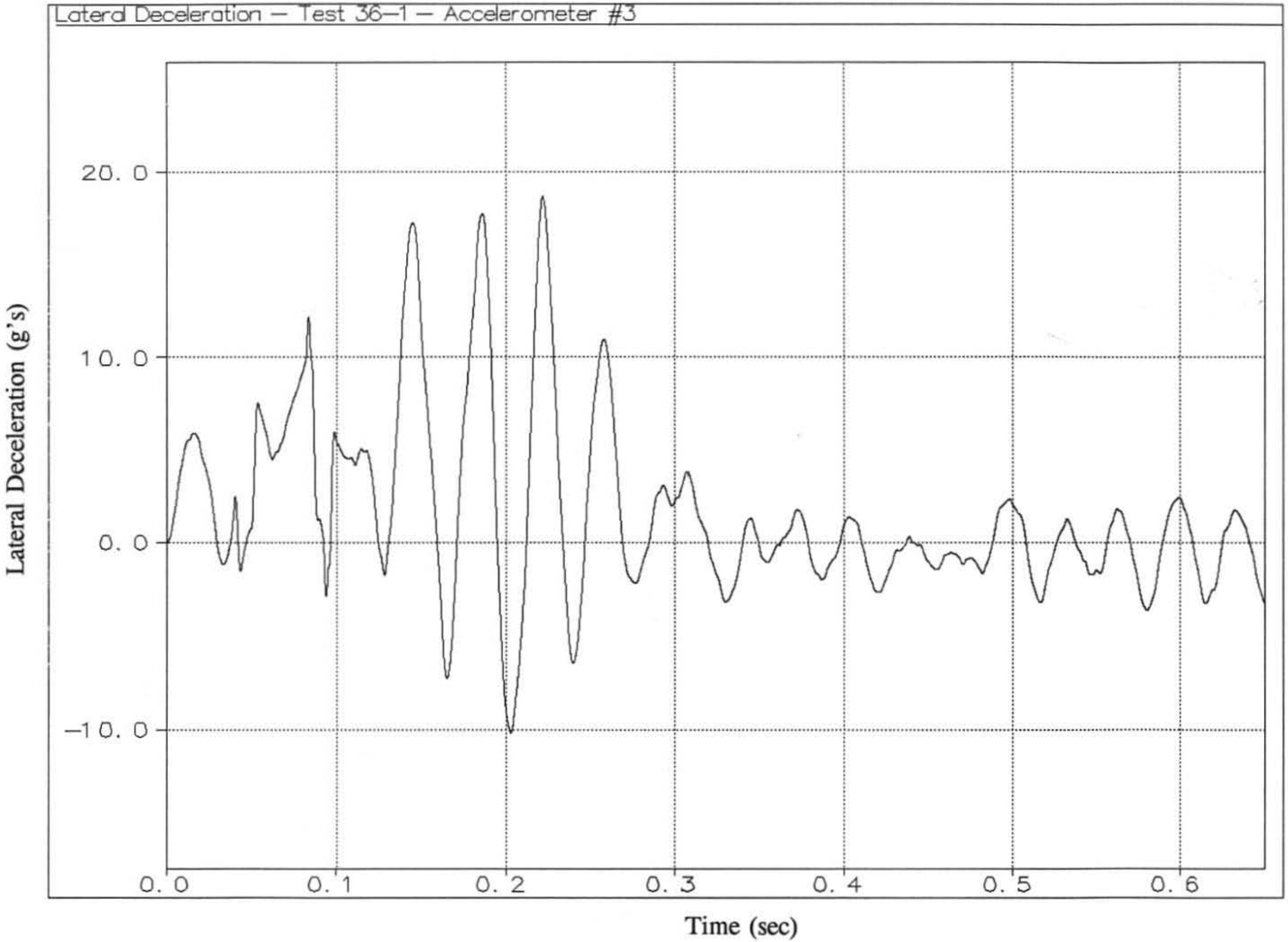


Figure A-2. Graph of Lateral Deceleration, Test 36-1