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16. Abstract

In December 2001, the Design Division and Bridge Division of Texas Department of Transportation released a new standard for an approach guardfence to concrete bridge rail transition that complies with the testing requirements of National Cooperative Highway Research Program (*NCHRP) Report 350* for use on high-speed roadways. Because there are no national transition designs that have been developed and tested for lower speed conditions, the same transition standard is typically applied to all roadways regardless of speed. However, the new thrie beam transition design represents a significant increase in installation cost and complexity over the previous design. Thus, it may be cost prohibitive to require use of the same design on all roadways. The purpose of this research was to develop a transition that is suitable for use on lower speed roadways and that is less expensive and complex than the current high-speed design. A low-cost transition was successfully evaluated at 45 mph impact speeds under *NCHRP Report 350* Test Level 2 conditions.

A second objective of the project was to evaluate the need for the curb detail that is one of the design elements of the newly adopted thrie beam transition design. Elimination of the curb would greatly enhance installation flexibility and reduce installation cost. The assessment of the curb was accomplished through full-scale crash testing.

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EVALUATION OF GUARDRAIL TO CONCRETE BRIDGE RAIL TRANSITIONS

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DISCLAIMER

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This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, and the U.S. Department of Transportation, Federal Highway Administration. The TxDOT project director for this research was Ms. Rory Meza, Design Division. Members of the project advisory committee included Mr. Bobby Dye, Design Division and Mr. Mark Bloschock, Bridge Division. The authors acknowledge and appreciate their guidance and assistance.

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CHAPTER 1. INTRODUCTION

BACKGROUND

On July 16, 1993, the Federal Highway Administration formally adopted the performance evaluation guidelines for highway safety features set forth in *National Cooperative Highway Research Program (NCHRP) Report 350* as a guide or reference document in *Federal Register, Volume 58, Number 135 (1)*. FHWA also mandated that, starting in September 1998, only highway safety appurtenances that meet the performance evaluation guidelines set forth in *NCHRP Report 350* may be used on new construction projects on the National Highway System (NHS).

Changes incorporated into the *NCHRP Report 350* guidelines included new design test vehicles, expanded test matrices, and revised impact conditions. Of most significance was the adoption of a ¾-ton (2000 kg) pickup truck as the design test vehicle for structural adequacy tests. This change has necessitated the retesting and redesign of many existing roadside safety features. As part of this process, TxDOT recently adopted a new transition from approach guardfence to concrete bridge rail that complies with *NCHRP Report 350* testing requirements.

TxDOT Standard Drawing MBGF(TR)-03, which was released in December 2001, provides details of this new metal beam guardfence transition. The design consists of a nested thrie beam rail supported on 7 ft (2.1 m) long steel or wood posts spaced at 18.75 in (476 mm). A 5.75 in (146 mm) tall Type II curb runs along the length of the nested thrie beam section. The front face of the curb is aligned with the traffic face of the wood blockout that offsets the thrie beam from the support posts. A thrie beam terminal connector is used to attach the downstream end of the transition to the concrete bridge rail parapet. On the upstream end, a 6 ft 3 in (1905 mm) 10 gauge thrie beam to W-beam transition element is used to transition the thrie beam to the standard W-beam rail section used in the approach guardfence.

Because this transition system was initially crash tested with a curb present, the FHWA approval of the system for use on federal-aid projects on the NHS is predicated on the presence of the curb. This curb requirement increases the cost and complexity of the transition installation, and requires modification of the bridge end drainage, particularly in retrofit and upgrade applications. If elimination of the curb can be achieved without compromising impact performance, it would greatly enhance installation flexibility and reduce installation cost of the transition.

Most transition systems are crash tested under Test Level (TL) 3 of *NCHRP Report 350*, which is the basic test level required to receive approval of the system for use on high-speed roadways. Since there are no national transition designs that have been developed for lower speed conditions, most states (including Texas) typically apply the same transition standard to all roadways regardless of speed. However, the new thrie beam transition design represents a significant increase in installation cost and complexity over the previous TxDOT transition. Thus, it may be cost prohibitive to require use of this system on low speed roadways. It is, therefore, desirable to design and test a transition suitable for use on lower speed roadways that is less expensive and complex than the high-speed thrie beam transition design.

OBJECTIVES/SCOPE OF RESEARCH

The primary purpose of this research was to develop a transition that is less expensive and complex than the recently adopted nested thrie beam design that is suitable for use on lower speed roadways. The performance of new transition design was evaluated both analytically and experimentally through full-scale crash testing to assess compliance with *NCHRP Report 350* performance criteria. The testing was conducted at an impact speed of 43.5 mi/h (70 km/h), which conforms to *NCHRP Report 350* TL-2 conditions. Approval as a TL-2 system would make the transition suitable for use on lower speed roadways.

A second objective of the project was to evaluate the need for the curb detail that is one of the design elements of the recently adopted nested thrie beam transition design. Elimination of the curb would greatly enhance installation flexibility and reduce installation cost. The assessment of the curb was accomplished through full-scale crash testing.

CHAPTER 2. CRASH TEST PROCEDURES

TEST FACILITY

The Texas Transportation Institute Proving Ground is a 2000-acre (809 hectare) complex of research and training facilities located 10 mi (16 km) northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for construction and testing of the bridge rail transitions evaluated under this project is along an out-of-service runway. The runway consists of an unreinforced jointed concrete pavement in 12.5 ft by 15 ft (3.8 m by 4.6 m) blocks nominally 8-12 in (203-305 mm) deep. The aprons and runways are about 50 years old, and the joints have some displacement, but are otherwise flat and level.

CRASH TEST CONDITIONS

The recommended test matrix for transitions consists of two tests:

***NCHRP Report 350* Test 21**: This test involves a 4409-lb (2000 kg) pickup truck impacting at the critical impact point (CIP) of the transition section at an angle of 25 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 4409-lb (2000 kg) vehicle.

***NCHRP Report 350* Test 20**: This test is optional and involves an 1808-lb (820 kg) passenger car impacting at the CIP of the transition section at an angle of 20 degrees. The test is intended to evaluate occupant risk and post-impact trajectory.

Test 21 was conducted for each of the transition designs evaluated in this project. The impact speed varied with the test level used to evaluate the transition. The nominal impact speed was 62.2 mph (100 km/h) for the TL-3 impact of the modified thrie beam transition without curb, and 43.5 mph (70 km/h) for the TL-2 transition. In accordance with the recommendations of *NCHRP Report 350*, the BARRIER VII simulation program was used to select the CIP for each test.

All crash test, data analysis, and evaluation and reporting procedures followed under this project were in accordance with guidelines presented in *NCHRP Report 350*. Appendix A presents brief descriptions of these procedures.

CHAPTER 3. MODIFIED THRIE BEAM TRANSITION

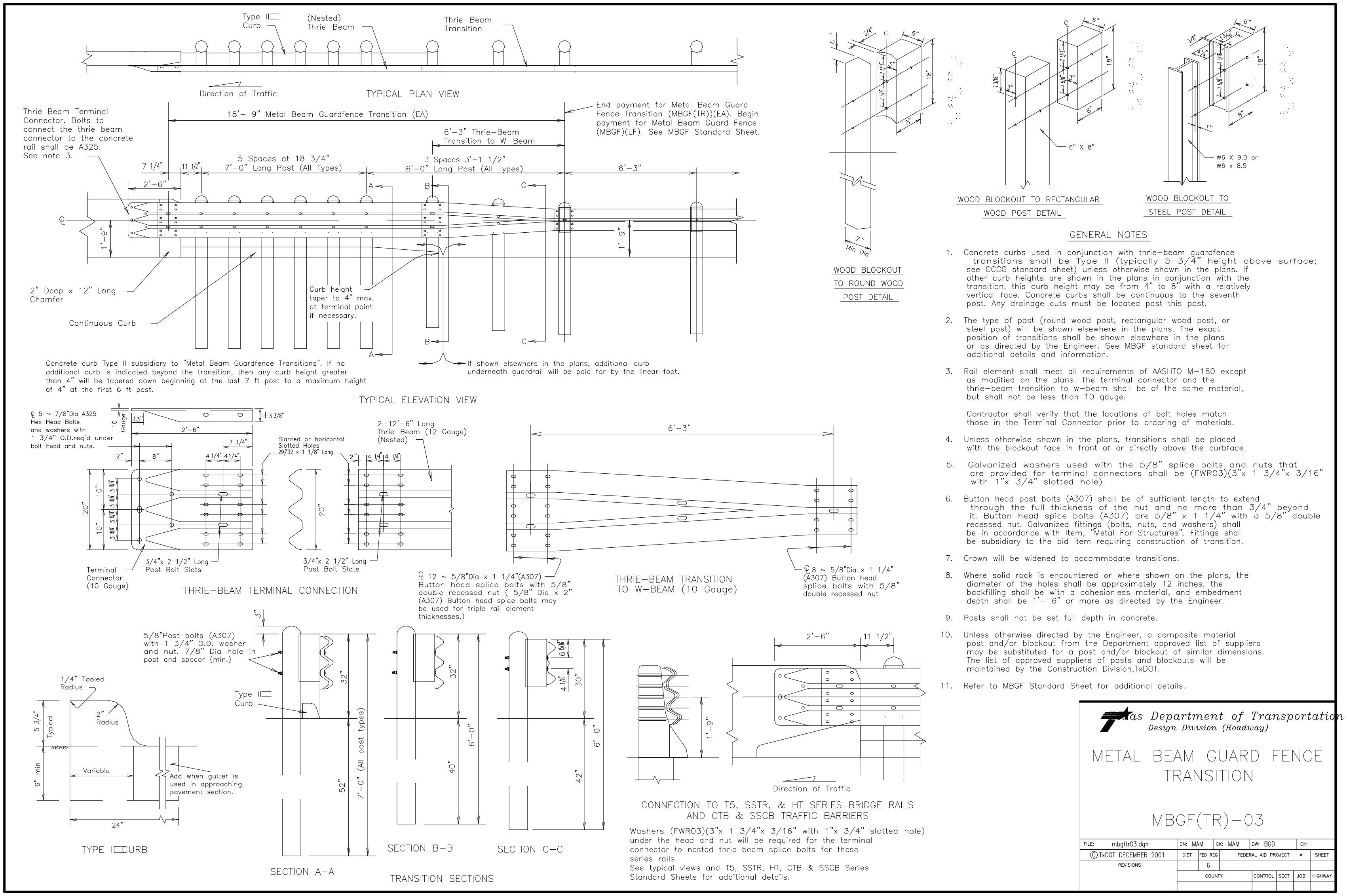
A full-scale crash test was conducted to determine if the Type II curb detail can be eliminated from the current nested thrie beam transition system without adversely affecting impact performance. With the exception of the curb detail, which was eliminated from the test installation, the thrie beam transition system was constructed following the details shown on Standard Drawing MBGF(TR)-03 which is reproduced as Figure 1. The standard detail sheet for the thrie beam transition permits use of three different post types: W6×9 (W150×14) steel posts, 7-in (178 mm) diameter round wood posts, and 6-in × 8-in (152 mm × 203 mm) rectangular wood posts. In consultation with TxDOT and FHWA's Office of Safety, it was determined that the W6×9 (W150×14) steel post would constitute the most critical condition in regard to post snagging and would, therefore, be used in the full-scale crash test. By using the most critical post type, it was agreed that a successful result would also be applicable to the other post types permitted in the standard.

Upon decision of the post type, a prototype transition installation was constructed to include an appropriate length of bridge parapet and approach guardfence, and a single guardrail terminal. The bridge parapet constructed for the test was a Type T501 traffic rail. Figure 2 shows details of the rail, taken from TxDOT standards. A 12.5-ft (3.8 m) long section of nested 12-gauge thrie beam rail was attached to the face of the Type T501 concrete parapet using a thrie beam terminal connector. The nested thrie beam rail was twisted toward the sloped traffic face of the parapet such that the terminal connector lay approximately flush with the surface of the parapet. The terminal connector was then attached to the parapet using five 0.825 in (21 mm) diameter, A325 hex head through bolts.

The transition and guardfence support posts were installed in *NCHRP Report 350* standard soil. The first post supporting the nested thrie beam transition section was located 11.5 in (292 mm) upstream from the end of the bridge rail end. The next five posts were spaced 18.75 in (476 mm) center to center. Each of these first six posts was 7 ft (2.1-m) long, W6×9 (150×14) steel posts embedded 52 in (1321 mm) below grade.

The nested thrie beam rail was transitioned to a single 12-gauge W-beam rail over a distance of 6 ft 3 in (1.9 m) using a 10-gauge, symmetrically tapered transition section. The three posts positioned along this section of the transition were 6 ft (1.8-m) long, W6×9 (W150×14) posts spaced at 37.5 in (953 mm) on center. Thus, there was a post on each end and midspan of the thrie beam to W-beam transition piece. Routed wood blockouts measuring 6 in × 8 in × 18 in (152 mm × 203 mm × 457 mm) were used along the length of the transition to offset the rail from the posts.

A 12.5-ft (3.8 m) length of standard metal beam guardfence was attached to the upstream end of the transition. The guardfence consisted of a 12-gauge W-beam rail supported on 6 ft (1.8 m) long, W6×9 (W150×14) steel posts spaced 6 ft 3 in (1.9-m). The W-beam rail was offset from the posts using 6 in × 8 in × 14 in (152 mm × 203 mm × 356 mm) routed wood blockouts. TxDOT standard sheet MBGF-03 contains further details of the metal beam guardfence. The



Washers (FWR03)(3"x 1 3/4"x 3/16" with 1"x 3/4" slotted hole) under the head and nut will be required for the terminal connector to nested thrie beam splice bolts for these series rails.
See typical views and T5, SSTR, HT, CTB & SSCB Series Standard Sheets for additional details.

GENERAL NOTES

1. Concrete curbs used in conjunction with thrie-beam guardfence transitions shall be Type II (typically 5 3/4" height above surface; see CCCG standard sheet) unless otherwise shown in the plans. If other curb heights are shown in the plans in conjunction with the transition, this curb height may be from 4" to 8" with a relatively vertical face. Concrete curbs shall be continuous to the seventh post. Any drainage cuts must be located past this post.

2. The type of post (round wood post, rectangular wood post, or steel post) will be shown elsewhere in the plans. The exact position of transitions shall be shown elsewhere in the plans or as directed by the Engineer. See MBGF standard sheet for additional details and information.

3. Rail element shall meet all requirements of AASHTO M-180 except as modified on the plans. The terminal connector and the thrie-beam transition to w-beam shall be of the same material, but shall not be less than 10 gauge.

   Contractor shall verify that the locations of bolt holes match those in the Terminal Connector prior to ordering of materials.

4. Unless otherwise shown in the plans, transitions shall be placed with the blockout face in front of or directly above the curbface.

5. Galvanized washers used with the 5/8" splice bolts and nuts that are provided for terminal connectors shall be (FWR03)(3"x 1 3/4"x 3/16" with 1"x 3/4" slotted hole).

6. Button head post bolts (A307) shall be of sufficient length to extend through the full thickness of the nut and no more than 3/4" beyond it. Button head spice bolts (A307) are 5/8" x 1 1/4" with a 5/8" double recessed nut. Galvanized fittings (bolts, nuts, and washers) shall be in accordance with Item, "Metal For Structures". Fittings shall be subsidiary to the bid item requiring construction of transition.

7. Crown will be widened to accommodate transitions.

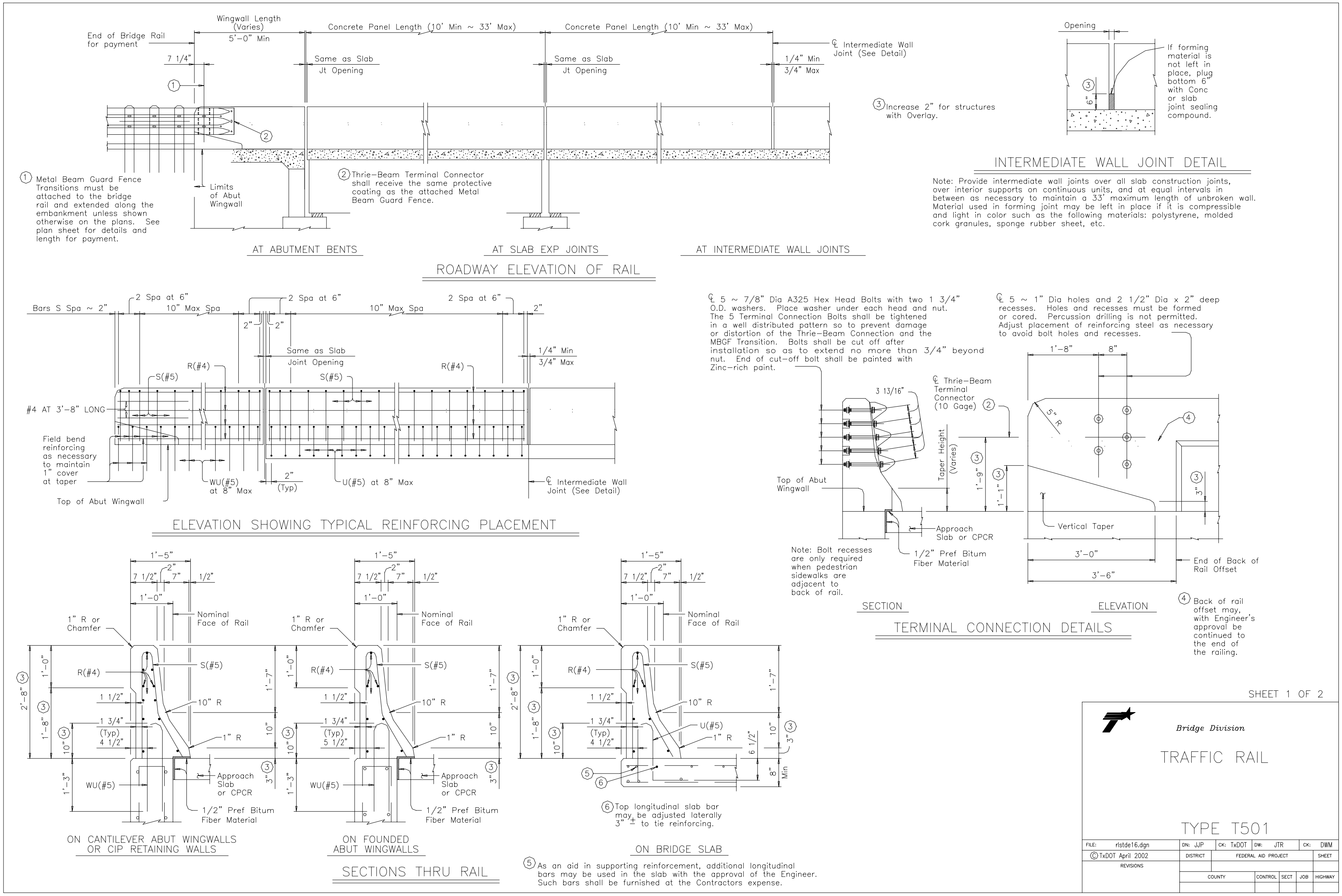
8. Where solid rock is encountered or where shown on the plans, the diameter of the holes shall be approximately 12 inches, the backfilling shall be with a cohesionless material, and embedment depth shall be 1'- 6" or more as directed by the Engineer.

9. Posts shall not be set full depth in concrete.

10. Unless otherwise directed by the Engineer, a composite material post and/or blockout from the Department approved list of suppliers may be substituted for a post and/or blockout of similar dimensions. The list of approved suppliers of posts and blockouts will be maintained by the Construction Division,TxDOT.

11. Refer to MBGF Standard Sheet for additional details.

Figure 1. Standard Drawing MBGF(TR)-03.



① Metal Beam Guard Fence Transitions must be attached to the bridge rail and extended along the embankment unless shown otherwise on the plans. See plan sheet for details and length for payment.

② Thrie-Beam Terminal Connector shall receive the same protective coating as the attached Metal Beam Guard Fence.

③ Increase 2" for structures with Overlay.

If forming material is not left in place, plug bottom 6" with Conc or slab joint sealing compound.

Note: Provide intermediate wall joints over all slab construction joints, over interior supports on continuous units, and at equal intervals in between as necessary to maintain a 33' maximum length of unbroken wall. Material used in forming joint may be left in place if it is compressible and light in color such as the following materials: polystyrene, molded cork granules, sponge rubber sheet, etc.

℄ 5 ~ 7/8" Dia A325 Hex Head Bolts with two 1 3/4" O.D. washers. Place washer under each head and nut. The 5 Terminal Connection Bolts shall be tightened in a well distributed pattern so to prevent damage or distortion of the Thrie-Beam Connection and the MBGF Transition. Bolts shall be cut off after installation so as to extend no more than 3/4" beyond nut. End of cut-off bolt shall be painted with Zinc-rich paint.

℄ 5 ~ 1" Dia holes and 2 1/2" Dia x 2" deep recesses. Holes and recesses must be formed or cored. Percussion drilling is not permitted. Adjust placement of reinforcing steel as necessary to avoid bolt holes and recesses.

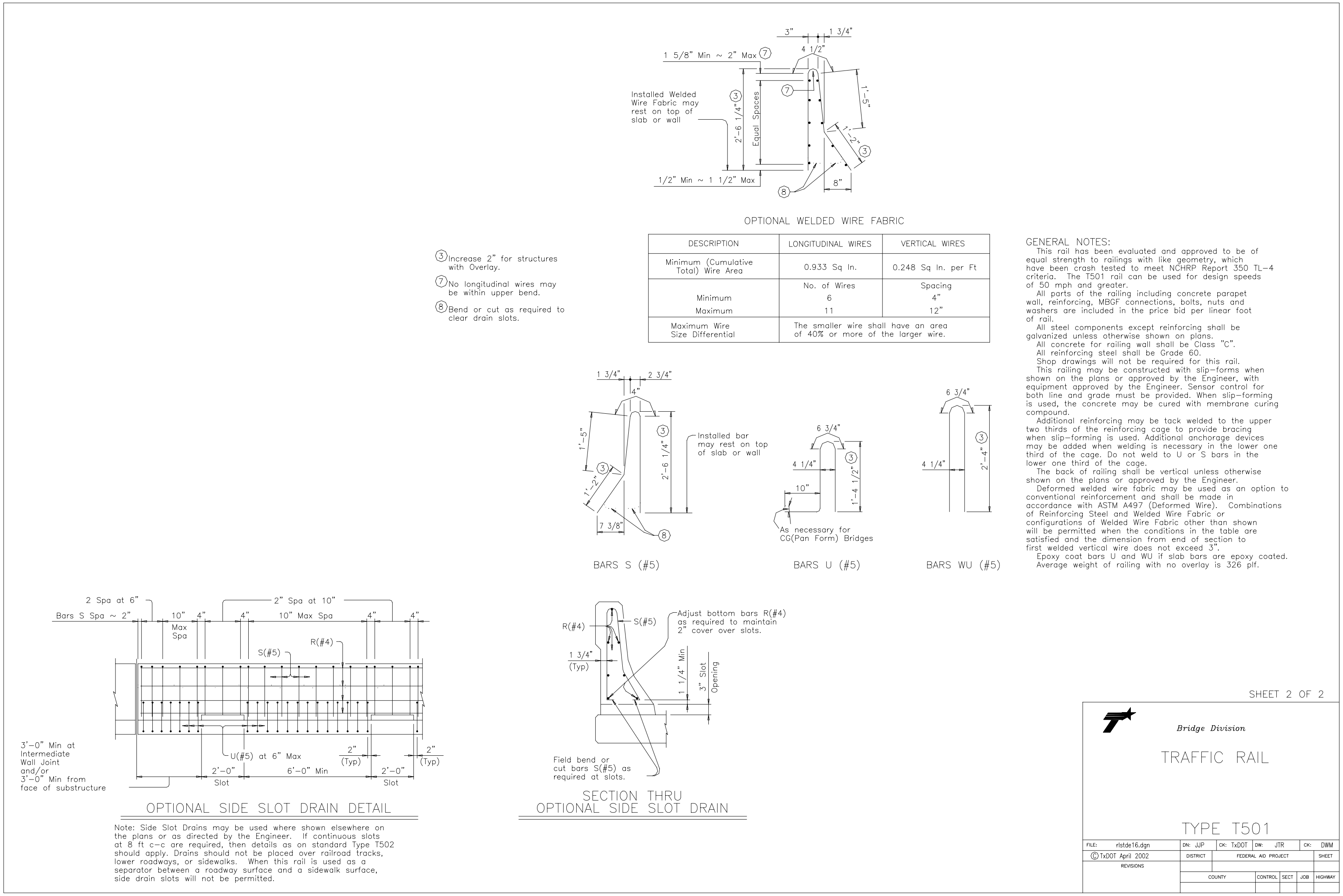
Note: Bolt recesses are only required when pedestrian sidewalks are adjacent to back of rail.

④ Back of rail offset may, with Engineer's approval be continued to the end of the railing.

⑥ Top longitudinal slab bar may be adjusted laterally 3" ± to tie reinforcing.

⑤ As an aid in supporting reinforcement, additional longitudinal bars may be used in the slab with the approval of the Engineer. Such bars shall be furnished at the Contractors expense.

Figure 2. Details of the T501 Bridge Rail.



OPTIONAL WELDED WIRE FABRIC

DESCRIPTION	LONGITUDINAL WIRES	VERTICAL WIRES
Minimum (Cumulative Total) Wire Area	0.933 Sq In.	0.248 Sq In. per Ft
	No. of Wires	Spacing
Minimum	6	4"
Maximum	11	12"
Maximum Wire Size Differential	The smaller wire shall have an area of 40% or more of the larger wire.	

③ Increase 2" for structures with Overlay.

⑦ No longitudinal wires may be within upper bend.

⑧ Bend or cut as required to clear drain slots.

GENERAL NOTES:

This rail has been evaluated and approved to be of equal strength to railings with like geometry, which have been crash tested to meet NCHRP Report 350 TL–4 criteria. The T501 rail can be used for design speeds of 50 mph and greater.

All parts of the railing including concrete parapet wall, reinforcing, MBGF connections, bolts, nuts and washers are included in the price bid per linear foot of rail.

All steel components except reinforcing shall be galvanized unless otherwise shown on plans.

All concrete for railing wall shall be Class "C".

All reinforcing steel shall be Grade 60.

Shop drawings will not be required for this rail.

This railing may be constructed with slip–forms when shown on the plans or approved by the Engineer, with equipment approved by the Engineer. Sensor control for both line and grade must be provided. When slip–forming is used, the concrete may be cured with membrane curing compound.

Additional reinforcing may be tack welded to the upper two thirds of the reinforcing cage to provide bracing when slip–forming is used. Additional anchorage devices may be added when welding is necessary in the lower one third of the cage. Do not weld to U or S bars in the lower one third of the cage.

The back of railing shall be vertical unless otherwise shown on the plans or approved by the Engineer.

Deformed welded wire fabric may be used as an option to conventional reinforcement and shall be made in accordance with ASTM A497 (Deformed Wire). Combinations of Reinforcing Steel and Welded Wire Fabric or configurations of Welded Wire Fabric other than shown will be permitted when the conditions in the table are satisfied and the dimension from end of section to first welded vertical wire does not exceed 3".

Epoxy coat bars U and WU if slab bars are epoxy coated.

Average weight of railing with no overlay is 326 plf.

Note: Side Slot Drains may be used where shown elsewhere on the plans or as directed by the Engineer. If continuous slots at 8 ft c–c are required, then details as on standard Type T502 should apply. Drains should not be placed over railroad tracks, lower roadways, or sidewalks. When this rail is used as a separator between a roadway surface and a sidewalk surface, side drain slots will not be permitted.

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REVISIONS

DISTRICT	FEDERAL AID PROJECT	SHEET

COUNTY	CONTROL	SECT	JOB	HIGHWAY

Figure 2. Details of the T501 Bridge Rail (Continued).

installation was terminated using a 37.5-ft (11.4 m) long Type I, ET-2000 PLUS single guardrail terminal. TxDOT standard sheet SGT(7)-03 shows details of the terminal. Figure 3 shows photographs of the completed test installation. Details of the test are provided below.

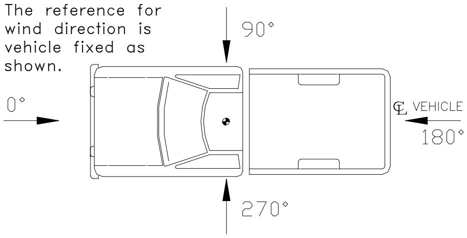
THRIE BEAM TRANSITION TEST (TEST NO. 445643-1)

Test Vehicle

A 1996 Chevrolet Cheyenne, shown in Figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 4504 lb (2045 kg), and its gross static weight was 4504 lb (2045 kg). The height to the lower edge of the vehicle bumper was 17.7 in (450 mm), and the height to the upper edge of the bumper was 26.0 in (660 mm). Appendix B, Figure 20 gives additional dimensions and information on the. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The test was performed on the morning of September 27, 2002. Moisture content of the *NCHRP Report 350* standard soil in which the device was installed was 6.8, 5.9, and 6.3 percent, at posts 12, 14, and 16, respectively. Weather conditions at the time of testing were as follows: Wind speed: 2 mi/h (1 km/h); wind direction: 180 degrees with respect to the vehicle (vehicle was traveling in a southeasterly direction); temperature: 86° F (30° C); relative humidity: 39 percent.



Test Description

The vehicle, traveling at a speed of 61.3 mi/h (98.7 km/h), impacted the transition 8.0 ft (2.435 m) upstream of the end of the concrete parapet at an impact angle of 24.7 degrees. Shortly after impact, posts 12 and 13 began to deflect toward the field side of the installation. At 0.010 seconds (s) after impact, post 14 began to deflect toward the field side, and at 0.015 s posts 15 and 11 deflected toward the field side. Post 16 deflected toward the field side at 0.107 s, and post 17 at 0.022 s. The vehicle began to redirect at 0.027 s. At 0.214 s, the vehicle became parallel with the rail and was traveling at a speed of 41.0 mi/h (65.9 km/h). The left rear of the vehicle contacted the rail at 0.244 s. At 0.572 s, the vehicle lost contact with the rail and was traveling at a speed of 40.2 mi/h (64.7 km/h) and an exit angle of 34.8 degrees. As the vehicle exited the test area, the right side wheels became airborne, and the vehicle began to roll counterclockwise and yaw clockwise. Brakes on the vehicle were not applied, and the vehicle subsequently came to rest on its left side 149.9 ft (45.7 m) downstream of impact and 32.5 ft (9.9 m) forward of the traffic face of the rail. Sequential photographs of the test period are shown in Appendix C, Figures 22 and 23.

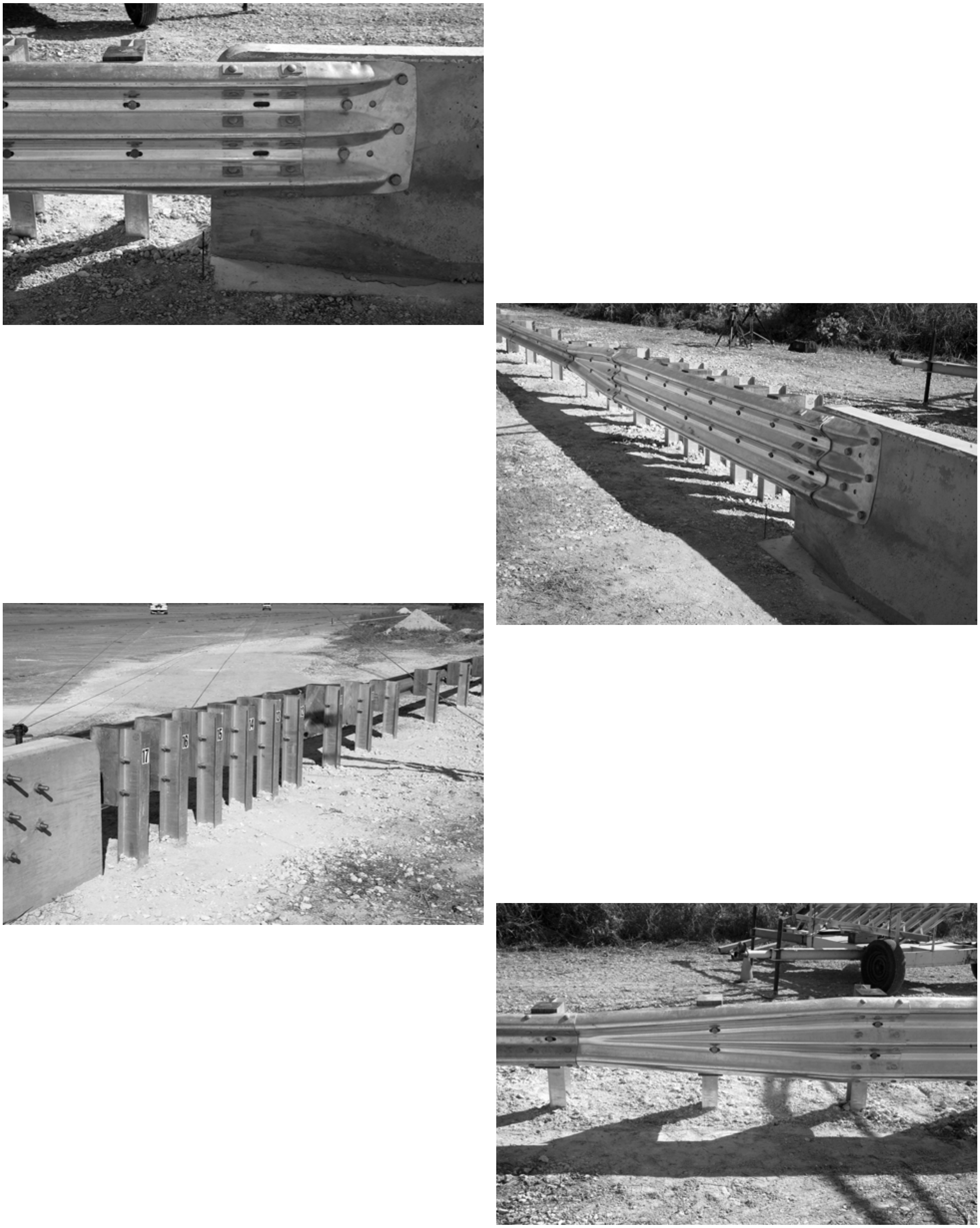


Figure 3. Thrie Beam Transition Prior to Test 445643-1.

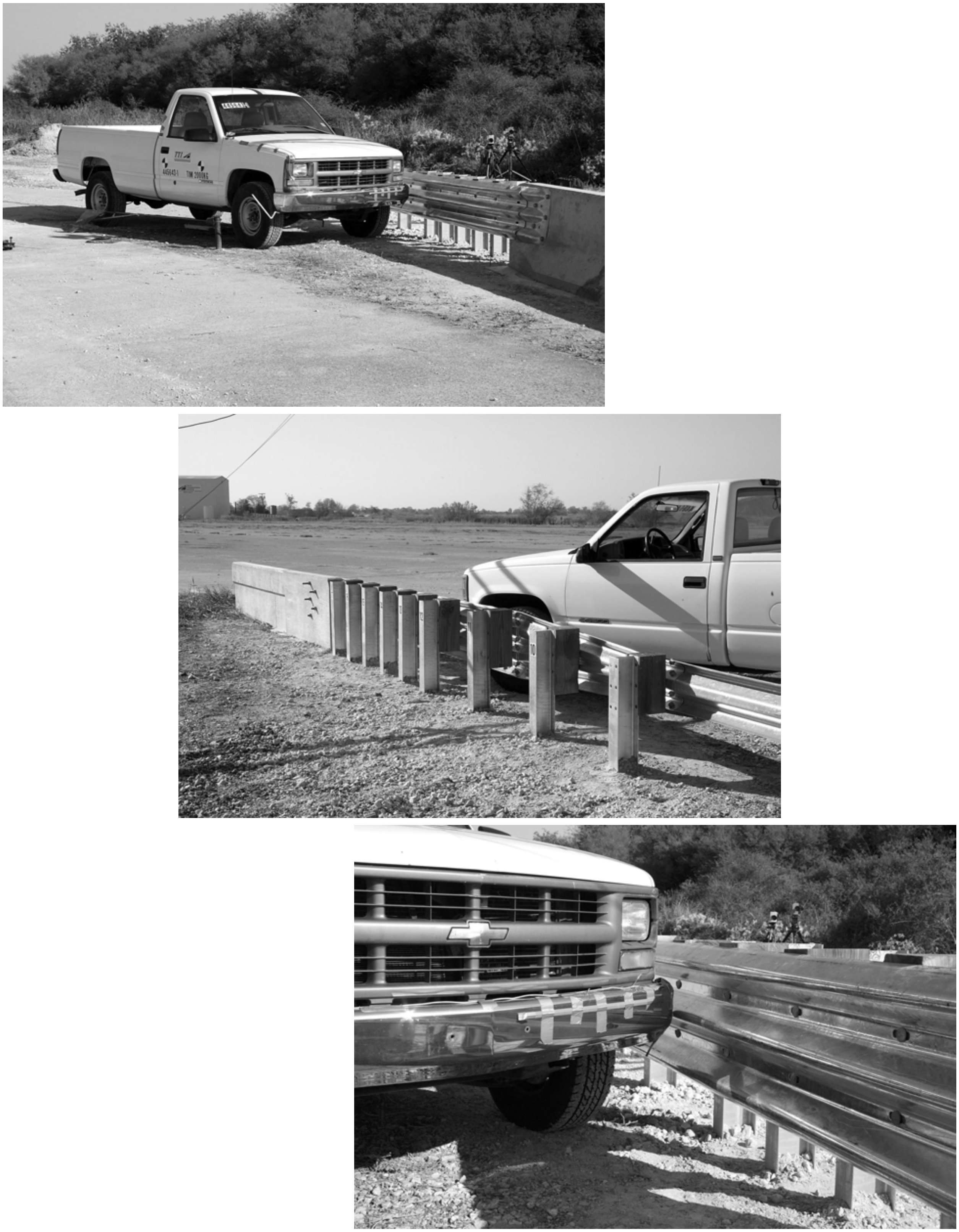


Figure 4. Vehicle/Installation Geometrics for Test 445643-1.

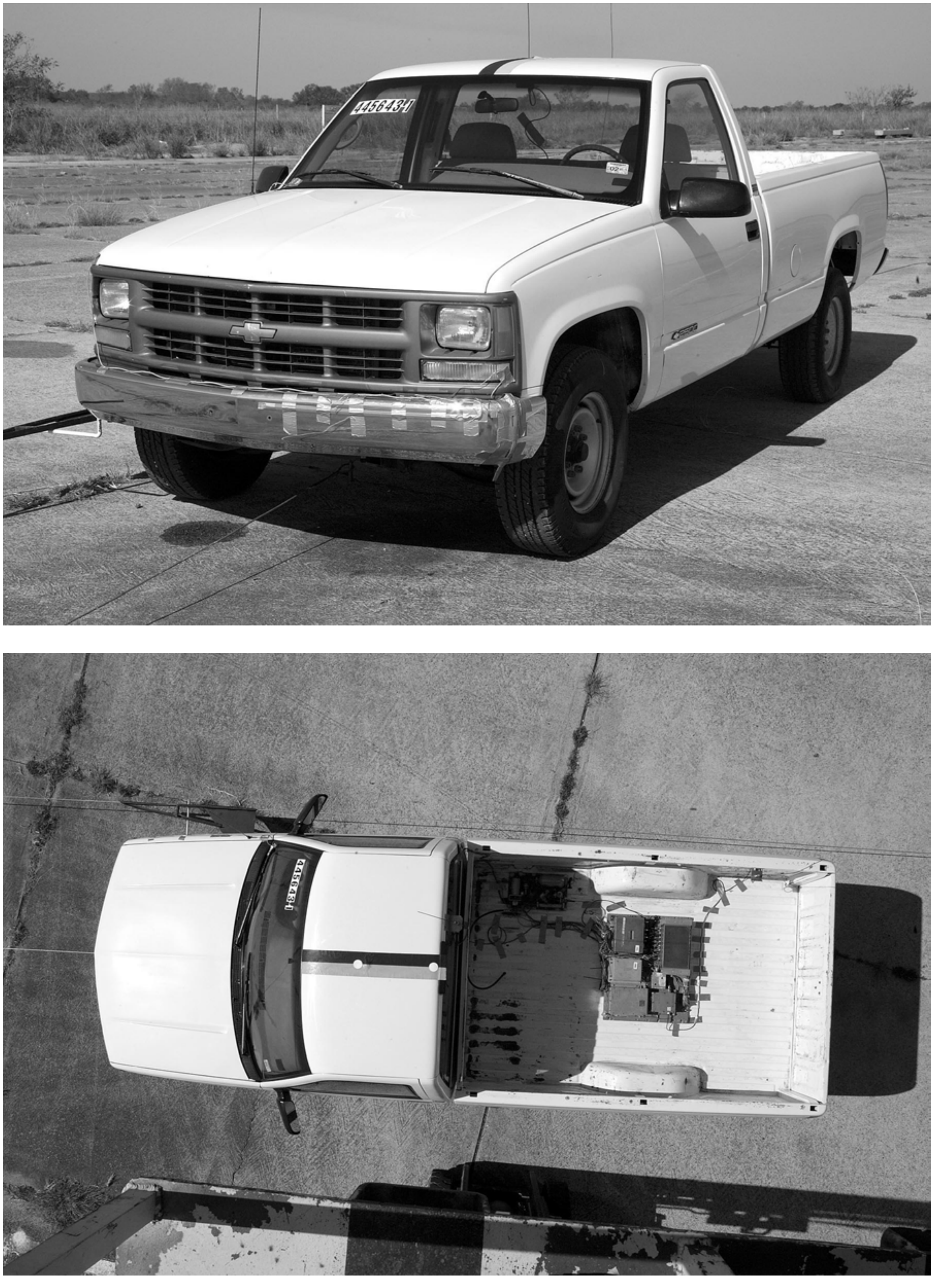


Figure 5. Vehicle before Test 445643-1.

Damage to Test Installation

Figures 6 and 7 show the transition sustained minimal damage. The lower edge of the thrie beam was folded under and flattened 2.4 in (60 mm) adjacent to the concrete parapet. Tire marks found on the end of the parapet extended 1.8 in (45 mm) from the traffic face, and compacted dirt extended another 1.8 in (45 mm) beyond the tire mark, for a total distance of 3.6 in (90 mm). The wood blockout at post 15 was split on the traffic face and the corners of the blockouts on posts 15 through 17 were shaved off approximately 1.6 in (40 mm). No tire marks were observed on the posts. Maximum dynamic deflection during the test was 4.1 inches (105 mm). Maximum residual deformation was 2.3 in (59 mm) between posts 15 and 16. Working width was 25 in (636 mm) and total length of contact of the vehicle with the transition was 135 in (3425 mm).

Vehicle Damage

The vehicle came to rest on its left side. Figure 8 shows photographs of the vehicle after it was uprighted. Structural damage was imparted to the left upper A-arm and ball joint, outer tie rod, left frame rail, sway bar and cross member. Also damaged were the front bumper, grill, radiator, fan, left front quarter panel, left door and glass, and left rear bed; and the right rear wheel rim was deformed. The windshield was cracked. The outer section of the left front wheel rim separated from the inner section by fracturing the rivets that held them together. Maximum exterior crush to the vehicle was 20.1 in (510 mm) in the frontal plane at the left front corner near bumper height. Within the occupant compartment, the instrument panel was deformed and the floor pan was deformed and separated at the seams in the left toe pan. Maximum occupant compartment deformation was 6.8 in (172 mm) in the center floorpan area over the transmission tunnel. Figure 9 shows photographs of the interior of the vehicle before and after the test. Appendix B, Tables 3 and 4 show occupant compartment and exterior vehicle deformation.

Occupant Risk Factors

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk criteria. Note that only the occupant impact velocity and ridedown accelerations in the longitudinal axis are required from these data for evaluation of criterion L of *NCHRP Report 350*; however, both longitudinal and lateral values are reported for informational purposes. In the longitudinal direction, the occupant impact velocity was 18.4 ft/s (5.6 meters/second (m/s)) at 0.101 s, the highest 0.010-s average occupant ridedown acceleration was -19.2 units of gravity (g's) from 0.101 to 0.111 s, and the maximum 0.050-s average acceleration was -9.8 g's between 0.097 and 0.147 s. In the lateral direction, the occupant impact velocity was 25.3 ft/s (7.7 m/s) at 0.101 s, the highest 0.010-s average occupant ridedown acceleration was 19.4 g's from 0.101 to 0.111 s, and the maximum 0.050-s average acceleration was 12.7 g's between 0.059 and 0.109 s. Figure 10 summarizes these data and other pertinent information from the. Vehicle angular displacements and accelerations versus time traces are presented in Appendix D, Figures 26, and 28 through 33, respectively.

Figure 6. After Impact Trajectory Path for Test 445643-1.

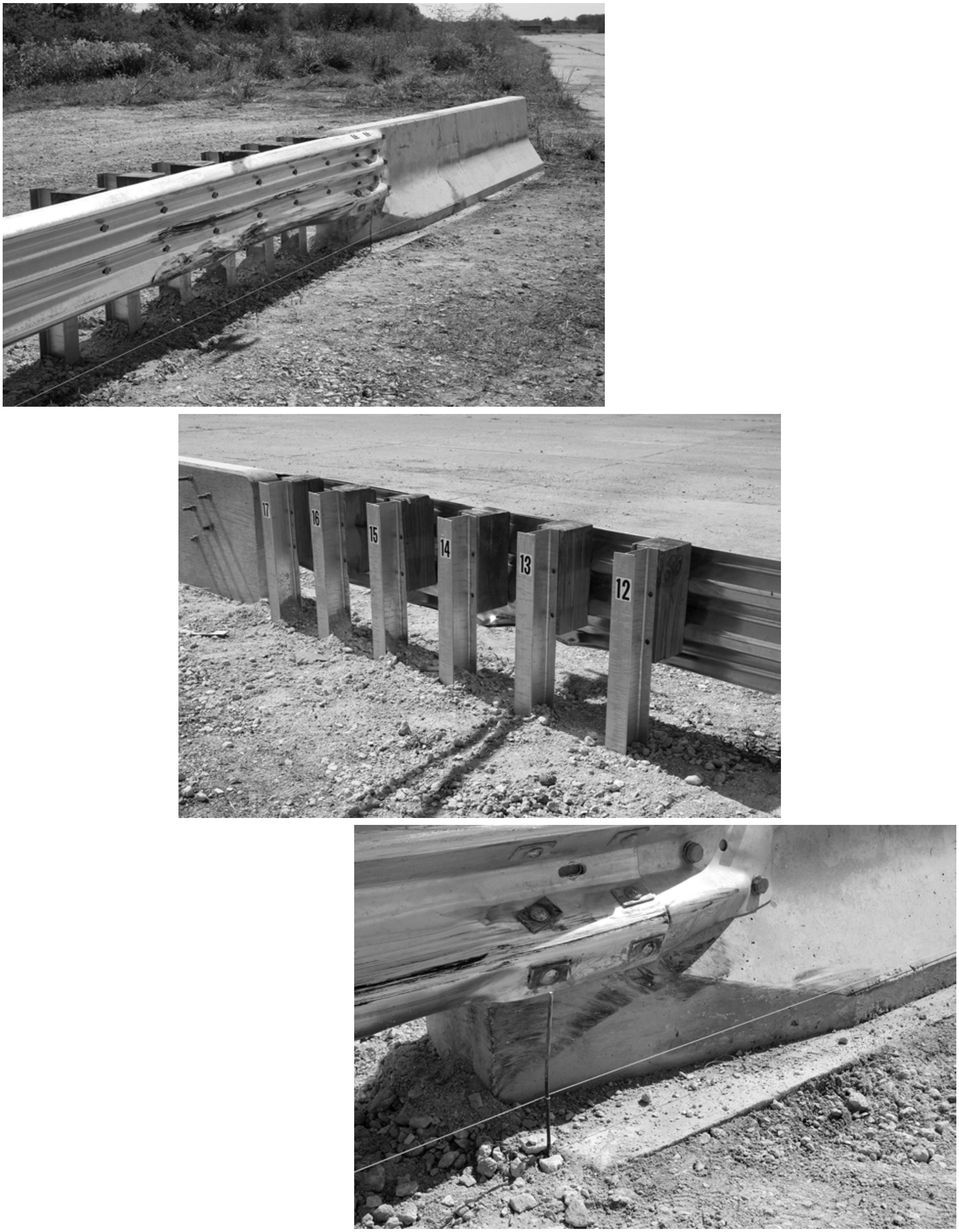


Figure 7. Installation after Test 445643-1.

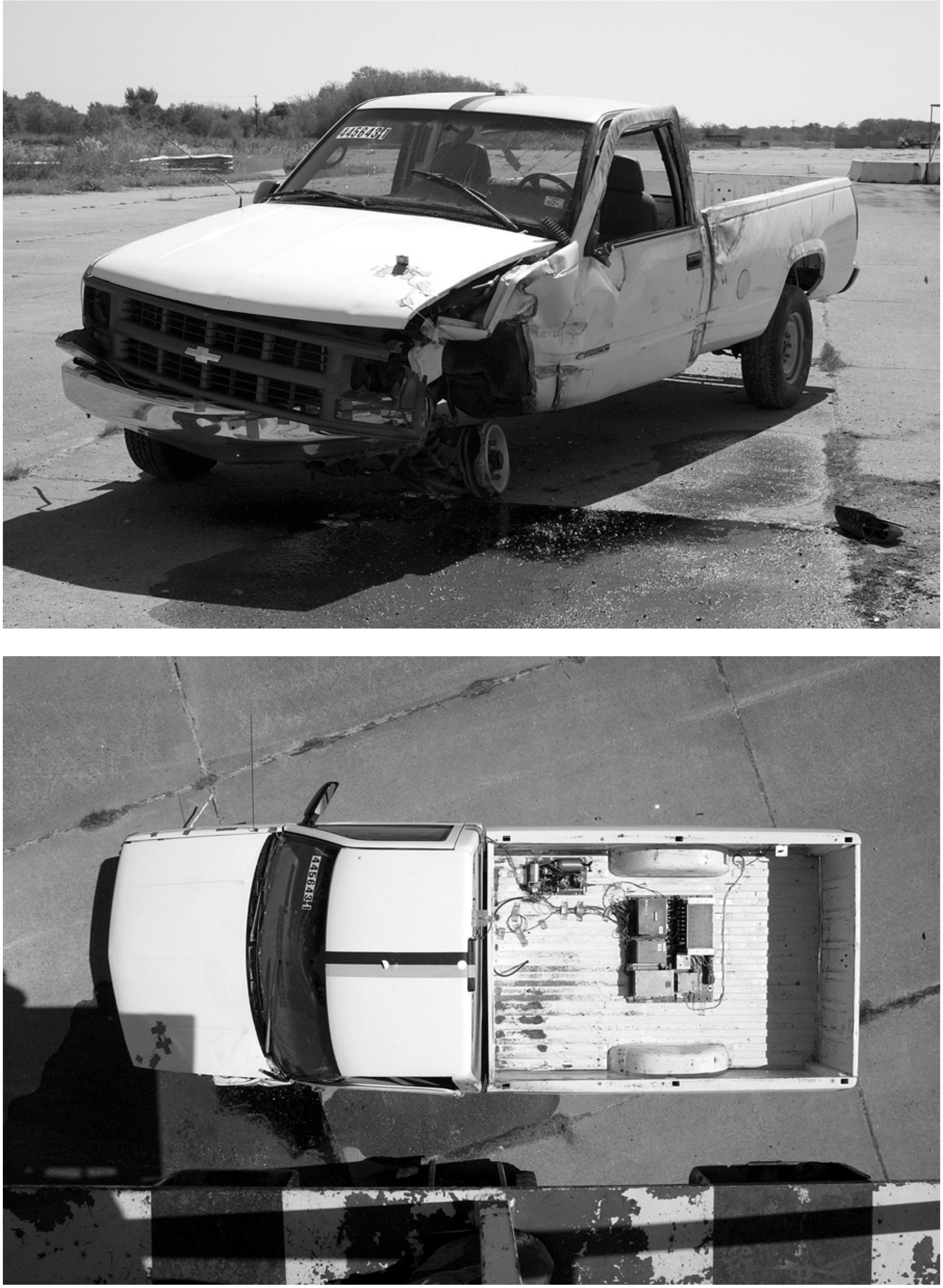
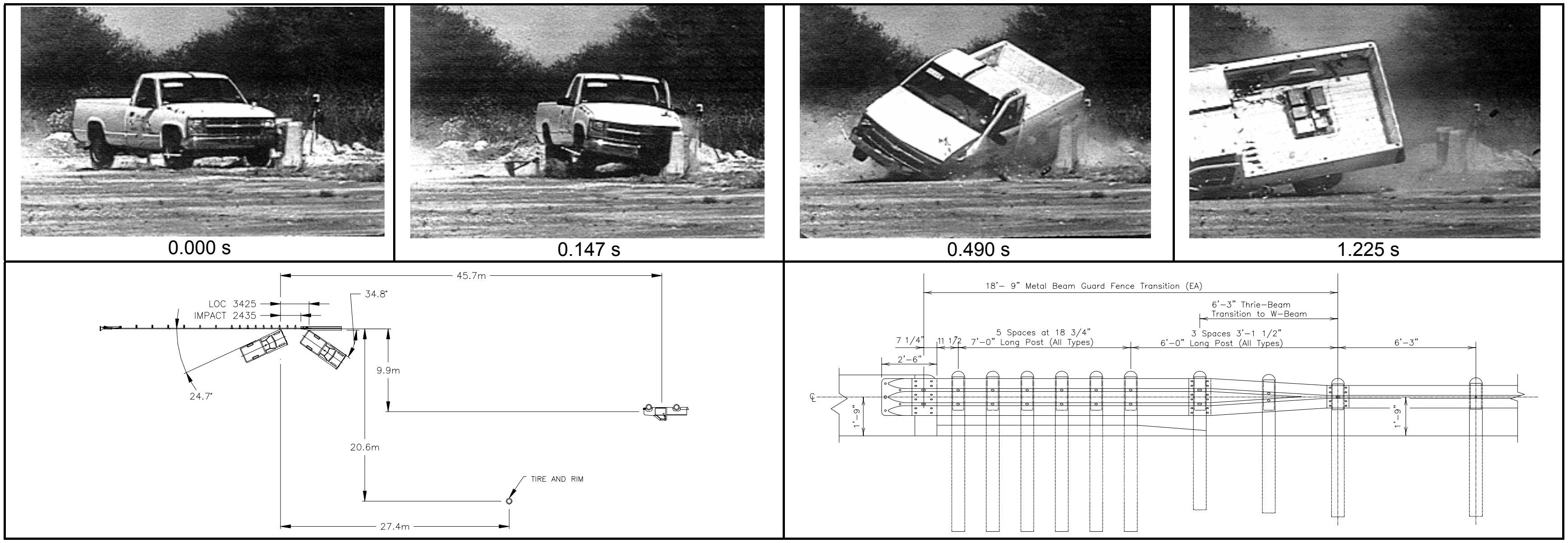


Figure 8. Vehicle after Test 445643-1.

Before Test

After Test

Figure 9. Interior of Vehicle for Test 445643-1.


0.000 s
0.147 s
0.490 s
1.225 s

General Information	
Test Agency	Texas Transportation Institute
Test No.	445643-1
Date	09/27/02
Test Article	
Type	Transition
Name	TxDOT Thrie Beam Transition
Installation Length (ft)	18.75 (5.72 m)
Material or Key Elements	T501 Concrete Parapet With Nested Thrie Beam Transition To W-Beam Rail
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1996 Chevrolet Cheyenne 2500 P/U
Mass (lb)	
Curb	4719 (2143 kg)
Test Inertial	4504 (2045 kg)
Dummy	N/A
Gross Static	4504 (2045 kg)

Impact Conditions	
Speed (mi/h)	61.3 (98.7 km/h)
Angle (deg)	24.7
Exit Conditions	
Speed (mi/h)	40.2 (64.7 km/h)
Angle (deg)	34.8
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	18.4 (5.6 m/s)
y-direction	25.3 (7.7 m/s)
THIV (mi/h)	20.5 (33.0 km/h)
Ridedown Accelerations (g's)	
x-direction	-19.2
y-direction	19.4
PHD (g's)	28.1
ASI	1.65
Max. 0.050-s Average (g's)	
x-direction	-9.8
y-direction	12.7
z-direction	-9.1

Test Article Deflections (in)	
Dynamic	4.1 (105 mm)
Permanent	2.3 (59 mm)
Working Width	25.0 (636 mm)
Vehicle Damage	
Exterior	
VDS	11FL3
CDC	11FLEW3
Maximum Exterior Vehicle Crush (in)	20.1 (510 mm)
Interior	
OCDI	LF0204000
Max. Occ. Compart. Deformation (in)	6.8 (172 mm)
Post-Impact Behavior	
(during 1.0 s after impact)	
Max. Yaw Angle (deg)	108.6
Max. Pitch Angle (deg)	-23.1
Max. Roll Angle (deg)	-76.2

Figure 10. Summary of Results for Test 445643-1, *NCHRP Report 350* Test 3-21.

Assessment of Test Results

An assessment of the test results based on the applicable *NCHRP Report 350* safety evaluation criteria is provided below.

Structural Adequacy

A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

Results: The transition contained and redirected the pickup truck. The pickup truck did not penetrate, underride, or override the installation. Maximum dynamic deflection of the transition during the test was 4.1 in (105 mm). *(PASS)*

Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

Results: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 6.8 in (172 mm) in the center floorpan area over the transmission tunnel. *(FAIL)*

F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

Results: The vehicle remained upright during the collision; however, the vehicle rolled onto its left side after loss of contact with the rail. *(FAIL)*

Vehicle Trajectory

K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.

Results: The vehicle came to rest on its left side 149.9 ft (45.7 m) downstream of impact and 32.5 ft (9.9 m) forward of the traffic face of the rail. *(FAIL)*

L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.

Results: Longitudinal occupant impact velocity was 18.4 ft/s (5.6 m/s) and longitudinal ridedown acceleration was -19.2 g's. *(PASS)*

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.

Results: Exit angle at loss of contact was 34.9 degrees, which was 141 percent of the impact angle. *(FAIL)*

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results, and those factors underlined pertain to the results of the test reported herein.

Passenger Compartment Intrusion

1. *Windshield Intrusion*
    - *a. No windshield contact*
    - *b. Windshield contact, no damage*
    - *c. Windshield contact, no intrusion*
    - *d. Device embedded in windshield, no significant intrusion*
    - *e. Complete intrusion into passenger compartment*
    - *f. Partial intrusion into passenger compartment*
2. *Body Panel Intrusion* *yes or no*

Loss of Vehicle Control

1. *Physical loss of control*
2. *Loss of windshield visibility*
3. *Perceived threat to other vehicles*
4. *Debris on pavement*

Physical Threat to Workers or Other Vehicles

1. *Harmful debris that could injure workers or others in the area*
2. *Harmful debris that could injure occupants in other vehicles*

No debris from the installation was present.

Vehicle and Device Condition

1. *Vehicle Damage*
    - *a. None*
    - *b. Minor scrapes, scratches or dents*
    - *c. Significant cosmetic dents*
    - *d. Major dents to grill and body panels*
    - *e. Major structural damage*
2. *Windshield Damage*
    - *a. None*
    - *b. Minor chip or crack*
    - *c. Broken, no interference with visibility*
    - *d. Broken or shattered, visibility restricted but remained intact*
    - *e. Shattered, remained intact but partially dislodged*
    - *f. Large portion removed*
    - *g. Completely removed*

3. Device Damage

- *a. None*
- *b. Superficial*
- *c. Substantial, but can be straightened*
- [✓ *d. Substantial, replacement parts needed for repair*]
- *e. Cannot be repaired*

CHAPTER 4. TL-2 TRANSITION

The researchers met with TxDOT personnel and discussed the design requirements and constraints associated with the development of a TL-2 transition from standard W-beam approach guardfence to a rigid concrete bridge parapet. Emphasis was placed on developing a system that is low cost and simple to install and maintain. Further, the project advisory panel instructed the researchers to design the system using standard TxDOT hardware items to the extent possible. It was also desirable for the height of the transition to be 27 in (686 mm). This height would greatly simplify the ability to connect the transition to existing 27-in (686 mm) tall bridge rails. Although a 27-in (686 mm) tall transition section was not feasible for TL-3 impact conditions, the reduced impact severity associated with the lower TL-2 impact speed makes a 27-in (686 mm) tall transition a realistic possibility.

Analyses were performed to assess the ability of selected design concepts to meet *NCHRP Report 350* impact performance criteria prior to conducting full-scale crash testing. Computer simulation techniques were used to support the analysis efforts. The program utilized in the computer modeling effort was BARRIER VII. BARRIER VII is a two-dimensional vehicle/barrier simulation program that has been widely used in the design and evaluation of flexible roadside barriers *(2)*. Variables that were investigated included post spacing and post size. Use of the simulation code provided more detailed understanding of the influence of these key transition design parameters on dynamic barrier deflection and the severity of wheel snagging on the end of the concrete parapet.

A final design was selected in consultation with the project advisory panel. Details of the selected design were then finalized and presented to the project advisory panel for review and approval prior to performance of the full-scale crash test. Upon approval of the design details, a prototype transition installation was constructed to include an appropriate length of bridge parapet and approach guardfence, and a single guardrail terminal. As with the TL-3 transition, it was determined that the W6×9 (W150×14) steel post would constitute the most critical condition in regard to post snagging and would, therefore, be used in the full-scale crash test. By using the most critical post type, a successful result would also be applicable to the wood posts used by TxDOT.

The bridge parapet constructed for the test was a 15-ft (4.6 m) long section of Type T501 traffic rail. A 12.5-ft (3.8 m) long section of nested 12-gauge W-beam rail was attached to the face of the T501 concrete parapet using a W-beam terminal connector. The nested W-beam rail was twisted into the sloped traffic face of the parapet and the terminal connector was attached to the parapet using four 0.825 in (21 mm)-diameter A325 hex head through bolts.

The nested W-beam was mounted to support posts at a height of 27 in (686 mm) to the top of the rail. The first post was located 27.5 in (686 mm) upstream from the end of the bridge rail end, and the next three posts comprising the transition were spaced 37.5 in (953 mm) apart. Each of the four posts in the transition section were standard 6-ft (1.8 m) long, W6×9 (W150×14) steel guardfence posts embedded 43 in (1092 mm) in *NCHRP Report 350* standard soil. The nested W-beam rail was offset from the posts using standard 6 in x 8 in x 14 in (152 mm × 203 mm × 356 mm) routed wood blockouts. Figure 11 shows details.

A 25-ft (7.6 m) length of standard metal beam guardfence was attached to the upstream end of the transition. It consisted of a single 12-gauge W-beam rail supported on W6×9 (W150×14) steel posts spaced 6 ft 3 in (1.9 m) apart. The W-beam rail was offset from the posts using 6 in × 8 in × 14 in (152 mm × 203 mm × 356 mm) routed wood blockouts. Further details of the metal beam guardfence can be found on TxDOT standard sheet MBGF-. The installation was terminated using a 37.5-ft (11.4 m) long Type I, ET-2000 PLUS single guardrail terminal. Details of the terminal can be found on TxDOT standard sheet SGT(7)-03. Figure 12 shows photographs of the completed test installation. A full-scale crash test was conducted to evaluate the safety performance of the TL-2 transition. Details of the test are provided below.

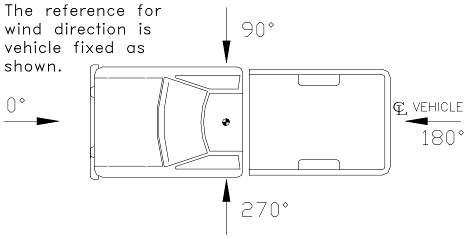
TL-2 TRANSITION TEST (TEST NO. 445643-2)

Test Vehicle

A 1998 Chevrolet Cheyenne, shown in Figures 13 and 14, was used for the crash test. Test inertia weight of the vehicle was 4515 lb (2050 kg), and its gross static weight was 4515 lb (2050 kg). The height to the lower edge of the vehicle bumper was 14.9 in (378 mm), and the height to the upper edge of the bumper was 23.4 in (595 mm). Appendix B, Figure 21 shows additional dimensions and information on the vehicle. The vehicle was directed into the installation using a cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

Soil and Weather Conditions

The test was performed on the morning of February 12, 2003. Moisture content of the *NCHRP Report 350* standard soil in which the device was installed was 7.0 percent. Weather conditions at the time of testing were as follows: Wind speed: 1.6 mi/h (2.5 km/h); wind direction: 0 degree with respect to the vehicle (vehicle was traveling in a southeasterly direction); temperature: 68° F (20° C); and relative humidity: 82 percent.



Test Description

The vehicle, traveling at a speed of 42.7 mi/h (68.8 km/h), impacted the transition 5.9 ft (1790 mm) upstream of the end of the concrete parapet at an impact angle of 26.8 degrees. Shortly after impact, posts 13 and 14 began to deflect toward the field side, and at 0.007 s, post 12 began to deflect toward the field side. The vehicle began to redirect at 0.037 s, and the left front tire contacted the end of the concrete parapet at 0.067 s. At 0.121 s, the left front tire

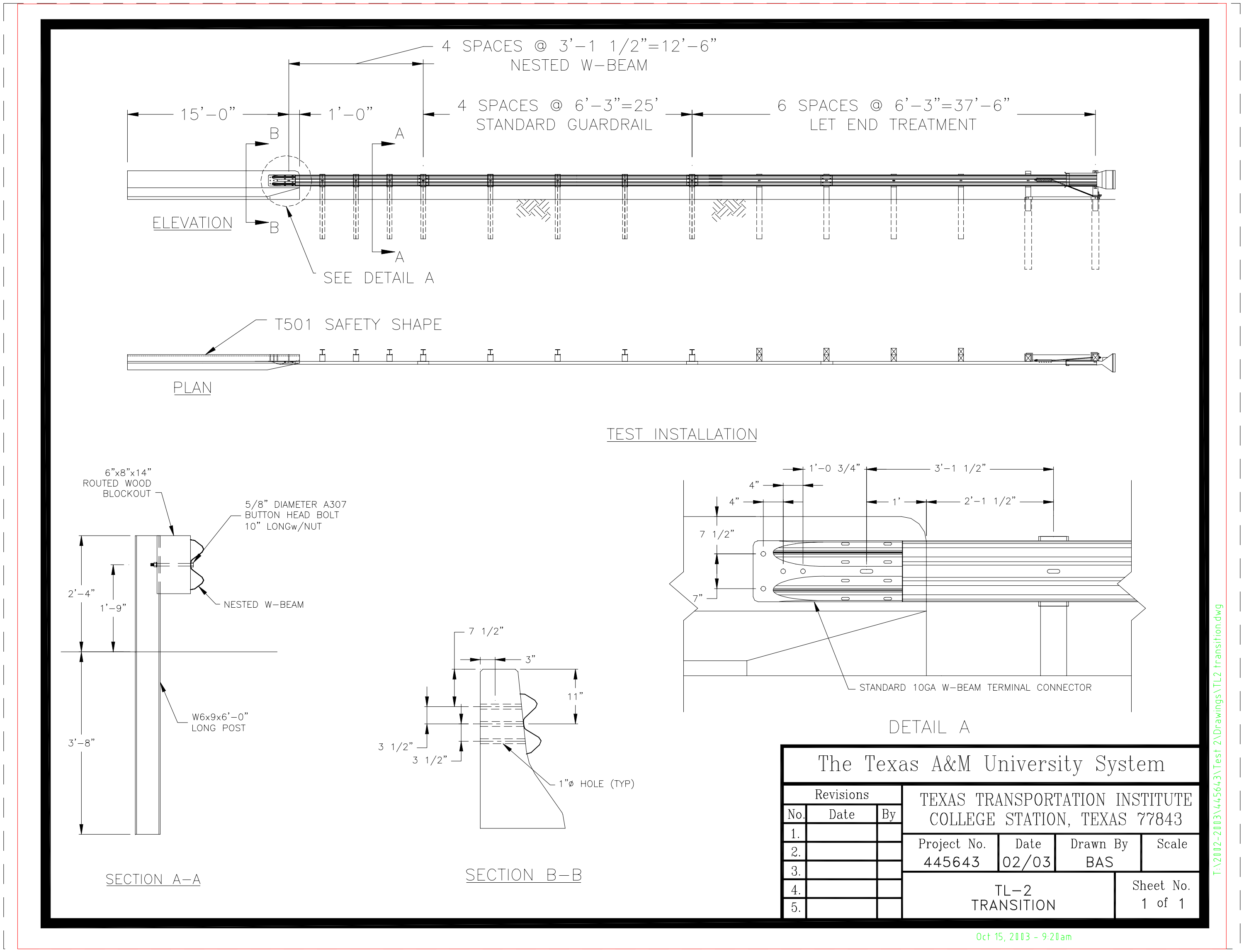


Figure 11. Details of the TL-2 Transition.

Figure 12. TL-2 Transition Prior to Test 445643-2.

Figure 13. Vehicle/Installation Geometrics for Test 445643-2.

Figure 14. Vehicle before Test 445643-2.

deflated, and at 0.233 s, the vehicle lost contact with the rail element. At 0.287 s, the vehicle was traveling parallel with the transition at a speed of 29.8 mi/h (47.9 km/h). The rear of the vehicle contacted the transition at 0.365 s and then contacted the end of the parapet at 0.392 s. At 0.557 s, the vehicle lost contact with the transition and was traveling at a speed of 27.4 mi/h (44.1 km/h) and an exit angle of 15.7 degrees. Brakes on the vehicle were applied 1.9 s after impact, and the vehicle subsequently came to rest upright 90 ft (27.4 m) downstream of impact and with the rear of the vehicle aligned with the traffic face of the rail. Appendix C, Figures 24 and 25 shows sequential photographs of the test period.

Damage to Test Installation

As Figures 15 and 16 show, the transition sustained minimal damage. The lower corrugation of the W-beam was gouged and flattened in the immediate vicinity of impact. Tire marks were found on the end of the parapet extending 3.5 in (90 mm) from the traffic face. There were no tire marks observed on the posts. Maximum dynamic deflection of the transition during the test was 2.6 in (65 mm). Maximum residual deformation was 1.6 in (42 mm) near post 13. Working width was 17.6 inches (448 mm), and total length of contact of the vehicle with the transition was 106 inches (2704 mm).

Vehicle Damage

Figure 17 shows the vehicle damage. Structural damage was imparted to the left lower A-arm, left outer tie rod end, left frame rail. Also damaged were the front bumper, grill, radiator, fan, left front quarter panel, left door, left rear bed, and rear bumper; and the right rear wheel rim was deformed. The windshield was stress-cracked. The left front tire was cut and the wheel rim was deformed. Maximum exterior crush to the vehicle was 17.7 in (450 mm) in the frontal plane at the left front corner near bumper height. In the occupant compartment, the floor pan was deformed and separated slightly at the seam with the left toe pan. Maximum occupant compartment deformation was 0.4 in (11 mm) in the left floorpan area. Figure 18 shows photographs of the interior of the vehicle, and Appendix B, Tables 5 and 6 shows occupant compartment and exterior vehicle deformation.

Occupant Risk Factors

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk criteria. Note that only the occupant impact velocity and ridedown accelerations in the longitudinal axis are required from these data for evaluation of criterion L of *NCHRP Report 350*; however, both longitudinal and lateral values are reported for information purposes. In the longitudinal direction, the occupant impact velocity was 18.7 ft/s (5.7 m/s) at 0.128 s, the highest 0.010-s occupant ridedown acceleration was -5.5 g's from 0.128 to 0.138 s, and the maximum 0.050-s average acceleration was -7.4 g's between 0.077 and 0.127 s. In the lateral direction, the occupant impact velocity was 20.7 ft/s (6.3 m/s) at 0.128 s, the highest 0.010-s occupant ridedown acceleration was 3.8 g's from 0.415 to 0.425 s, and the maximum

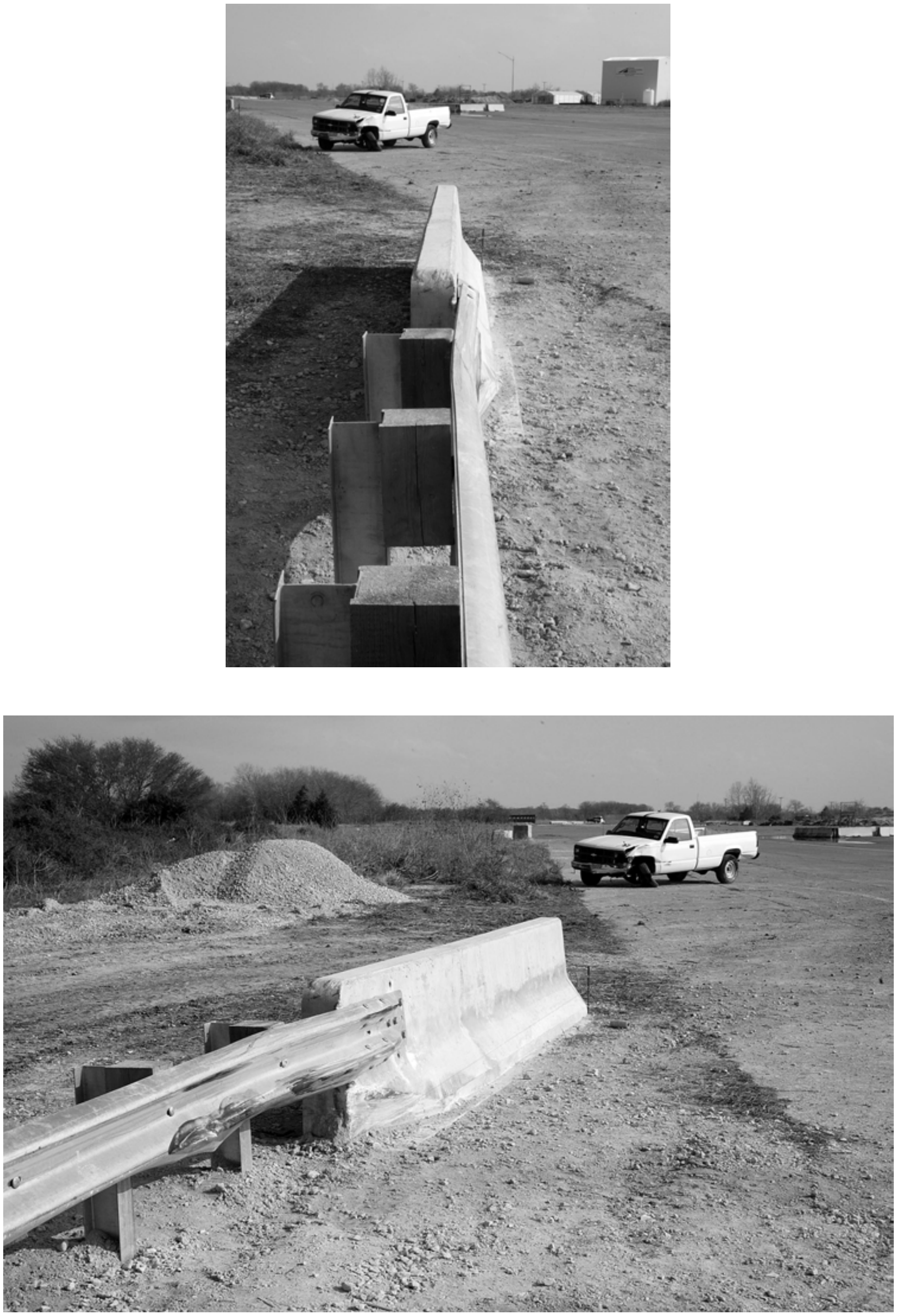


Figure 15. After Impact Trajectory Path for Test 445643-2.

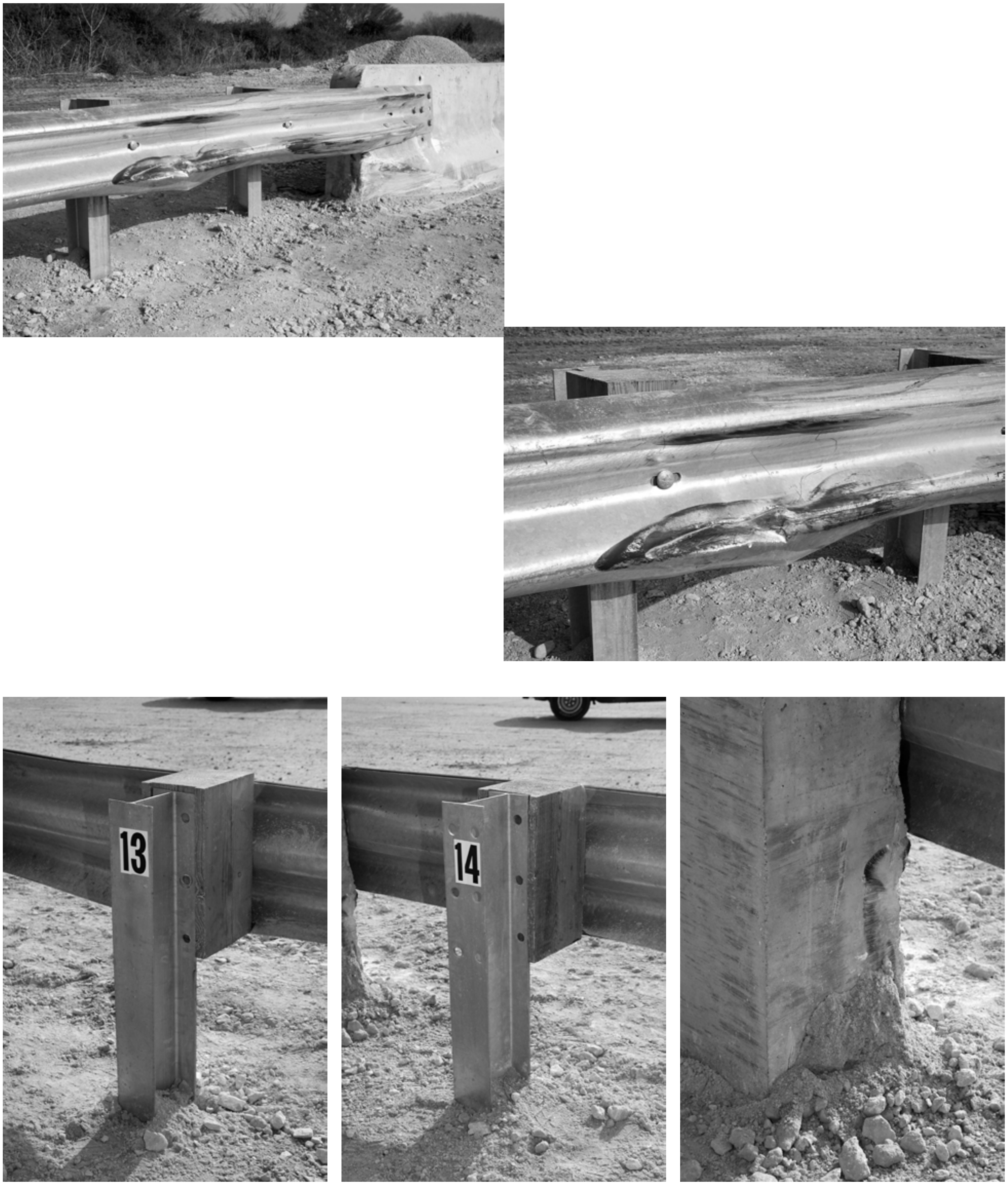


Figure 16. Installation after Test 445643-2.

Figure 17. Vehicle after Test 445643-2.

Before Test

After Test

Figure 18. Interior of Vehicle for Test 445643-2.

0.050-s average was 8.0 g's between 0.069 and 0.119 s. Figure 19 summarizes these data and other pertinent information from the test. Vehicle angular displacements and accelerations versus time traces are presented in Appendix D, Figures 27, and 34 through 39, respectively.

Assessment of Test Results

An assessment of the test based on the applicable *NCHRP Report 350* safety evaluation criteria is provided below.

Structural Adequacy

A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.

Results: The transition contained and redirected the pickup truck. The pickup truck did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.6 in (65 mm). *(PASS)*

Occupant Risk

D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.

Results: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 0.4 in (11 mm) in the left floorpan area. *(PASS)*

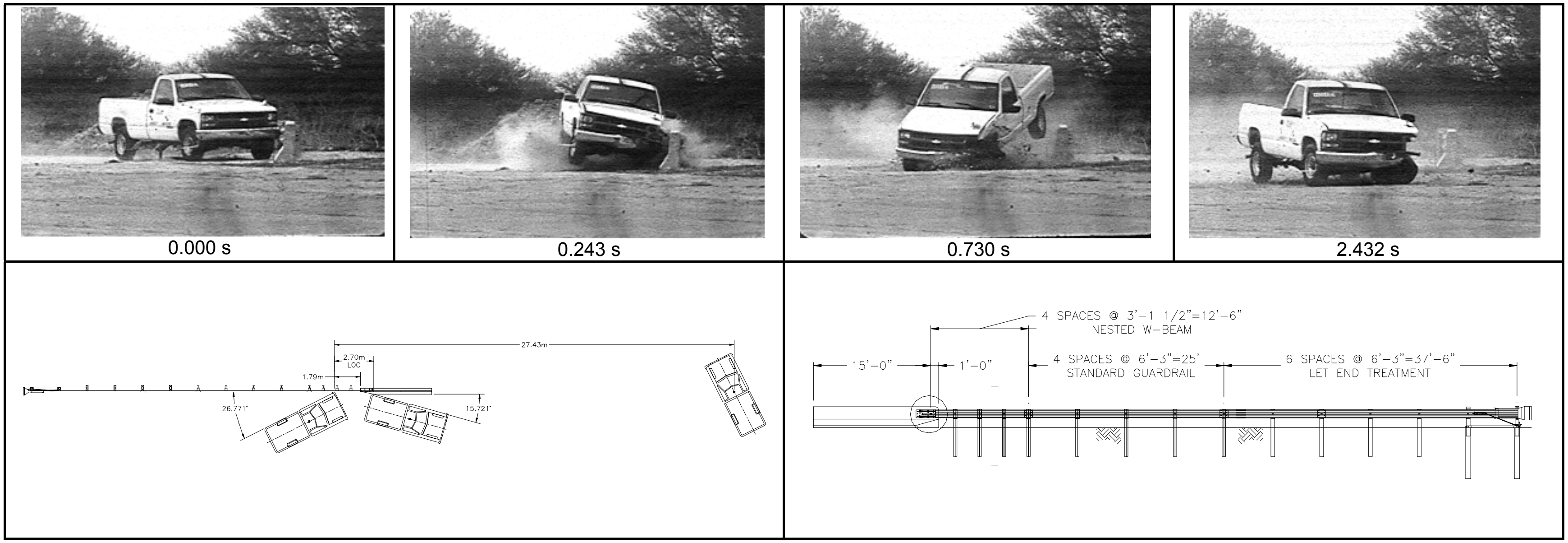
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.

Results: The vehicle remained upright during and after the collision event. *(PASS)*

Vehicle Trajectory

K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.

Results: The vehicle came to rest upright 90 ft (27 m) downstream of impact with the rear of the vehicle aligned with the traffic face of the rail. *(PASS)*



General Information	
Test Agency	Texas Transportation Institute
Test No.	445643-2
Date	02/12/03
Test Article	
Type	Transition
Name	TxDOT TL-2 Transition
Installation Length (ft)	12.5 (3.8 m)
Material or Key Elements	T501 Concrete Parapet With Nested W-Beam Transition
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1998 Chevrolet Cheyenne 2500 P/U
Mass (lb)	
Curb	4862 (2208 kg)
Test Inertial	4515 (2050 kg)
Dummy	N/A
Gross Static	4515 (2050 kg)

Impact Conditions	
Speed (mi/h)	42.7 (68.8 km/h)
Angle (deg)	26.8
Exit Conditions	
Speed (mi/h)	27.4 (44.1 km/h)
Angle (deg)	15.7
Occupant Risk Values	
Impact Velocity (ft/s)	
x-direction	18.7 (5.7 m/s)
y-direction	20.7 (6.3 m/s)
THIV (mi/h)	17.9 (28.9 km/h)
Ridedown Accelerations (g's)	
x-direction	-5.5
y-direction	3.8
PHD (g's)	9.2
ASI	1.07
Max. 0.050-s Average (g's)	
x-direction	-7.4
y-direction	8.0
z-direction	-3.0

Test Article Deflections (in)	
Dynamic	2.6 (65 mm)
Permanent	1.6 (42 mm)
Working Width	17.6 (448 mm)
Vehicle Damage	
Exterior	
VDS	11FL3
CDC	11FLEW3
Maximum Exterior Vehicle Crush (in)	17.7 (450 mm)
Interior	
OCDI	LF0001000
Max. Occ. Compart. Deformation (in)	0.4 (11 mm)
Post-Impact Behavior	
(during 1.0 s after impact)	
Max. Yaw Angle (deg)	44.0
Max. Pitch Angle (deg)	-9.8
Max. Roll Angle (deg)	-13.4

Figure 19. Summary of Results for Test 445643-2, *NCHRP Report 350* Test 2-21.

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.

Results: Longitudinal occupant impact velocity was 18.7 ft/s (5.7 m/s) and longitudinal ridedown acceleration was -5.5 g's. *(PASS)*

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.

Results: Exit angle at loss of contact was 15.7 degrees which was 59 percent of the impact angle. *(PASS)*

The following supplemental evaluation factors and terminology, as presented in the FHWA memo entitled "Action: Identifying Acceptable Highway Safety Features," were used for visual assessment of test results, and those factors underlined pertain to the results of the test reported herein.

Passenger Compartment Intrusion

1. *Windshield Intrusion*
    - *a. No windshield contact*
    - *b. Windshield contact, no damage*
    - *c. Windshield contact, no intrusion*
    - *d. Device embedded in windshield, no significant intrusion*
    - *e. Complete intrusion into passenger compartment*
    - *f. Partial intrusion into passenger compartment*
2. *Body Panel Intrusion* *yes* *or* *no*

Loss of Vehicle Control

1. *Physical loss of control*
2. *Loss of windshield visibility*
3. *Perceived threat to other vehicles*
4. *Debris on pavement*

Physical Threat to Workers or Other Vehicles

1. *Harmful debris that could injure workers or others in the area*
2. *Harmful debris that could injure occupants in other vehicles*

No debris from the installation was present.

Vehicle and Device Condition

1. *Vehicle Damage*
    - *a. None*
    - *b. Minor scrapes, scratches or dents*
    - *c. Significant cosmetic dents*
    - *d. Major dents to grill and body panels*
    - *e. Major structural damage*

2. *Windshield Damage*
    - *a. None*
    - *b. Minor chip or crack (stress only)*
    - *c. Broken, no interference with visibility*
    - *d. Broken or shattered, visibility restricted but remained intact*
    - *e. Shattered, remained intact but partially dislodged*
    - *f. Large portion removed*
    - *g. Completely removed*
3. *Device Damage*
    - *a. None*
    - *b. Superficial*
    - *c. Substantial, but can be straightened*
    - *d. Substantial, replacement parts needed for repair*
    - *e. Cannot be repaired*

CHAPTER 5. SUMMARY AND CONCLUSIONS

THRIE BEAM TRANSITION WITHOUT CURB

In response to FHWA requirements to use *NCHRP Report 350* compliant roadside safety devices on the National Highway System, TxDOT adopted a nested thrie beam transition for use on its high-speed roadways. Because this transition system was initially crash tested with a curb present, the FHWA approval for the system is predicated on the presence of the curb. This curb requirement increases the cost and complexity of the transition installation, and requires modification of the bridge end drainage, particularly in retrofit and upgrade applications. Elimination of the curb would greatly enhance installation flexibility and reduce installation cost.

An assessment of the need for the curb was accomplished through a full-scale crash test. As shown in Table 1, the nested thrie beam transition without curb did not meet the requirements of *NCHRP Report 350*. The vehicle rolled onto its left side as it exited the test site, and occupant compartment deformation was 6.8 in (172 mm), which is more than the 6.0 in (150 mm) considered acceptable by FHWA.

Further research is needed to determine if other design modifications would enable the transition to meet impact performance requirements without the Type II curb. Possible alternatives include the addition of a lower rubrail, and/or incorporating a blockout to offset the nested thrie beam from the face of the concrete parapet. These alternatives are intended to mitigate the snagging contact between the vehicle and the end of the concrete bridge rail, thus improving vehicle stability and reducing occupant compartment deformation.

TL-2 TRANSITION

Most states, including Texas, have typically applied the same transition standard to all roadways regardless of speed. However, in order to meet *NCHRP Report 350* impact performance requirements for TL-3 impact conditions, transition systems had to be raised in height and considerably stiffened. As a result, the new nested thrie beam transition design adopted by TxDOT represents a significant increase in installation cost and complexity over the previous TxDOT transition. Thus, it becomes cost prohibitive to require use of this system on low-speed roadways.

A new TL-2 nested W-beam transition was developed for use on roadways with speeds of 45 mi/h (70 km/h) or less. As summarized in Table 2, the new TL-2 nested W-beam transition met all the requirements of *NCHRP Report 350*. This transition is entirely comprised of standard hardware components and is significantly less expensive and complex than the high-speed thrie beam transition system. Damage to the system after the design crash test was relatively minor and required only minimal repair, indicating that the transition should be easy to maintain.

Table 1. Performance Evaluation Summary for Test 445643-1, *NCHRP Report 350* Test 3-21.

Test Agency: Texas Transportation Institute Test No.: 445643-1 Test Date: 09/27/2002

NCHRP Report 350 **Test 3-21 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The transition contained and redirected the pickup truck. Maximum dynamic deflection during the test was 4.1 in (105 mm).	Pass
Occupant Risk D. *Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 6.8 in (172 mm) in the center floorpan area over the transmission tunnel.	Fail
F. *The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.*	The vehicle remained upright during the collision; however, the vehicle rolled onto its left side after loss of contact with the rail.	Fail
Vehicle Trajectory K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*	The vehicle came to rest on its left side 149.9 ft (45.7 m) downstream of impact and 32.5 ft (9.9 m) forward of the traffic face of the rail.	Fail*
L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*	Longitudinal occupant impact velocity was 18.4 ft/s (5.6 m/s) and longitudinal ridedown acceleration was -19.2 g's.	Pass
M. *The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.*	Exit angle at loss of contact was 34.9 degrees, which was 141 percent of the impact angle.	Fail*

* Criterion K and M preferable, not required.

Table 2. Performance Evaluation Summary for Test 445643-2, *NCHRP Report 350* Test 2-21.

Test Agency: Texas Transportation Institute Test No.: 445643-2 Test Date: 02/12/2003

NCHRP Report 350 **Test 2-21 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.*	The transition contained and redirected the pickup truck. The pickup truck did not penetrate, underride, or override the installation. Maximum dynamic deflection during the test was 2.6 in (65 mm).	Pass
Occupant Risk D. *Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 0.4 in (11 mm) in the left floorpan area.	Pass
F. *The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.*	The vehicle remained upright during and after the collision event.	Pass
Vehicle Trajectory K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*	The vehicle came to rest upright 90 ft (27 m) downstream of impact with the rear of the vehicle aligned with the traffic face of the rail.	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 18.7 ft/s (5.7 m/s) and longitudinal ridedown acceleration was -5.5 g's.	Pass
M. *The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.*	Exit angle at loss of contact was 15.7 degrees which was 59 percent of the impact angle.	Pass*

* Criterion K and M preferable, not required.

CHAPTER 6. IMPLEMENTATION STATEMENT

Under this project, the impact performance of two transition systems was evaluated according to *NCHRP Report 350* criteria. These include a modification to the existing thrie beam transition that eliminated the Type II curb detail, and a new TL-2 transition design for use on lower speed roadways (45 mi/h or less).

THRIE BEAM TRANSITION WITHOUT CURB

Crash testing demonstrated that the nested thrie beam transition does not meet the requirements of *NCHRP Report 350* when the Type II curb is not present and is, therefore, not suitable for implementation. The current metal beam guardfence transition design, detailed on TxDOT standard MBGF(TR)-03, should continue to be used on high-speed roadways when warranted.

Further research is needed to determine if other design modifications would enable the transition to meet impact performance requirements without the Type II curb. Possible alternatives include the addition of a lower rubrail, or incorporating a blockout to offset the nested thrie beam from the face of the concrete parapet. These alternatives are intended to mitigate the snagging contact between the vehicle and the end of the concrete bridge rail.

TL-2 TRANSITION

A new TL-2 nested W-beam transition was successfully developed and found to meet the impact performance requirements of *NCHRP Report 350*. Statewide implementation of the new TL-2 nested W-beam transition system has been accomplished through the development of a new standard detail sheet (MBGF(TL2)-03) by personnel in TxDOT's Design Division. It is considered suitable for use on roadways with speeds of 45 mi/h (70 km/h) or less.

The transition is entirely comprised of standard hardware components and represents a significant savings in terms of both material and installation cost compared to the high-speed nested thrie beam transition. The 27-in (686 mm) mounting height greatly simplifies the ability to connect the transition to existing bridge rails. The minor damage sustained by the system during the design crash test suggests that the transition should also be easy to maintain.

REFERENCES

1. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer and J. D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program Report 350, Transportation Research Board, National Research Council, Washington, D.C., 1993.

2. G. H. Powell, *BARRIER VII: A Computer Program for Evaluation of Automobile Barrier Systems*, Report No. FHWA-RD-73-51, Federal Highway Administration, Washington, D.C., April 1973.

APPENDIX A. 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.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a backup biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO® Model 2262CA, piezoresistive accelerometers with a ±100g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Angular rate transducers are solid state, gas flow units designed for high-"g" service. Signal conditioners and amplifiers in the test vehicle increase the low-level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-cal (resistive calibration) or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15-channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals from the test vehicle are recorded before the test and immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle 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 produces an "event" mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto separate tracks of a 28-track, (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R-cal and pre-zero values at 10,000 samples per second per channel. WinDigit also provides Society of Automotive Engineers (SAE) J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to the SAE J211 *4.6.1* by means of an ENDEVCO® 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results are factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data is suspect.

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. WinDigit calculates 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 are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots 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 systems being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350* and there was no dummy used in the tests with the 2000P vehicle.

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; one placed behind the installation at an angle; and 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 tape switches 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 16-mm movie cine, a BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

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 it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

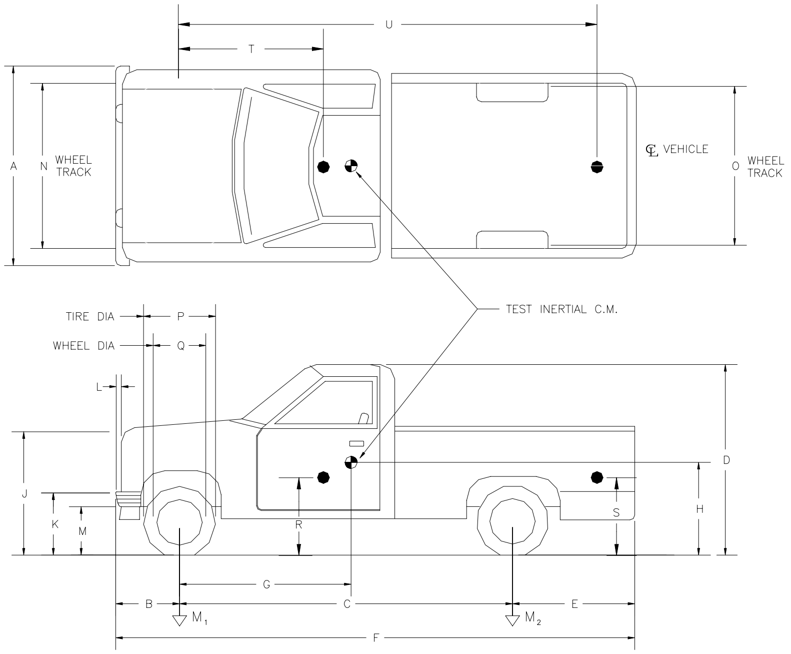
DATE: 09/27/02 TEST NO.: 445643-1 VIN NO.: 1GCGC24R3TZ111393

YEAR: 1996 MAKE: Chevrolet MODEL: Cheyenne 2500 Pickup

TIRE INFLATION PRESSURE: ________ ODOMETER: 133472 TIRE SIZE: 245 75 R16

MASS DISTRIBUTION (kg) LF 575 RF 580 LR 445 RR 445

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ___________

ENGINE TYPE: V-8

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

__ AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

8 LUGS

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY – (mm)

A	1880	E	1310	J	1090	N	1590	R	680
B	810	F	5470	K	660	O	1610	S	900
C	3350	G	1457.9	L	70	P	725	T	1455
D	1835	H		M	450	Q	440	U	3400

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1225	1155	
M_2	918	890	
M_T	2143	2045	

Figure 20. Vehicle Properties for Test 445643-1.

Table 3. Exterior Crush Measurements for Test 445643-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________	Bowing: B1 _____ X1 _____
Corner shift: A1 ________	B2 _____ X2 _____
A2 ________	
End shift at frame (CDC)	Bowing constant
(check one)	$\frac{X1+X2}{2}$ = _______
< 4 inches ________	
≥ 4 inches ________	

Note: All measurements in metric.
Note: Measure C_1 to C_6 from Driver to Passenger side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	At front bumper	1000	510	600	510	440	320	160	70	0	+300
2	At front bumper	1000	460	1400	0	110	N/A	N/A	290	460	+1525

[1] Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc.
Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

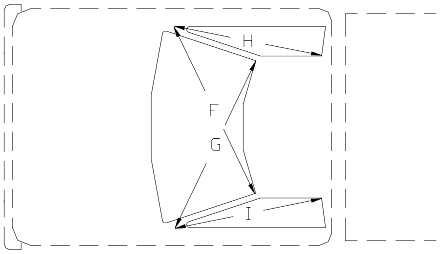
***Measure and document on the vehicle diagram the location of the maximum crush.

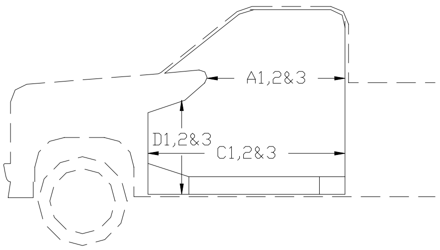
Note: Use as many lines/columns as necessary to describe each damage profile.

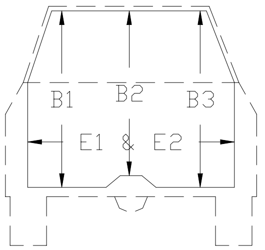
Table 4. Occupant Compartment Measurements for Test 445643-1.

Truck

Occupant Compartment Deformation

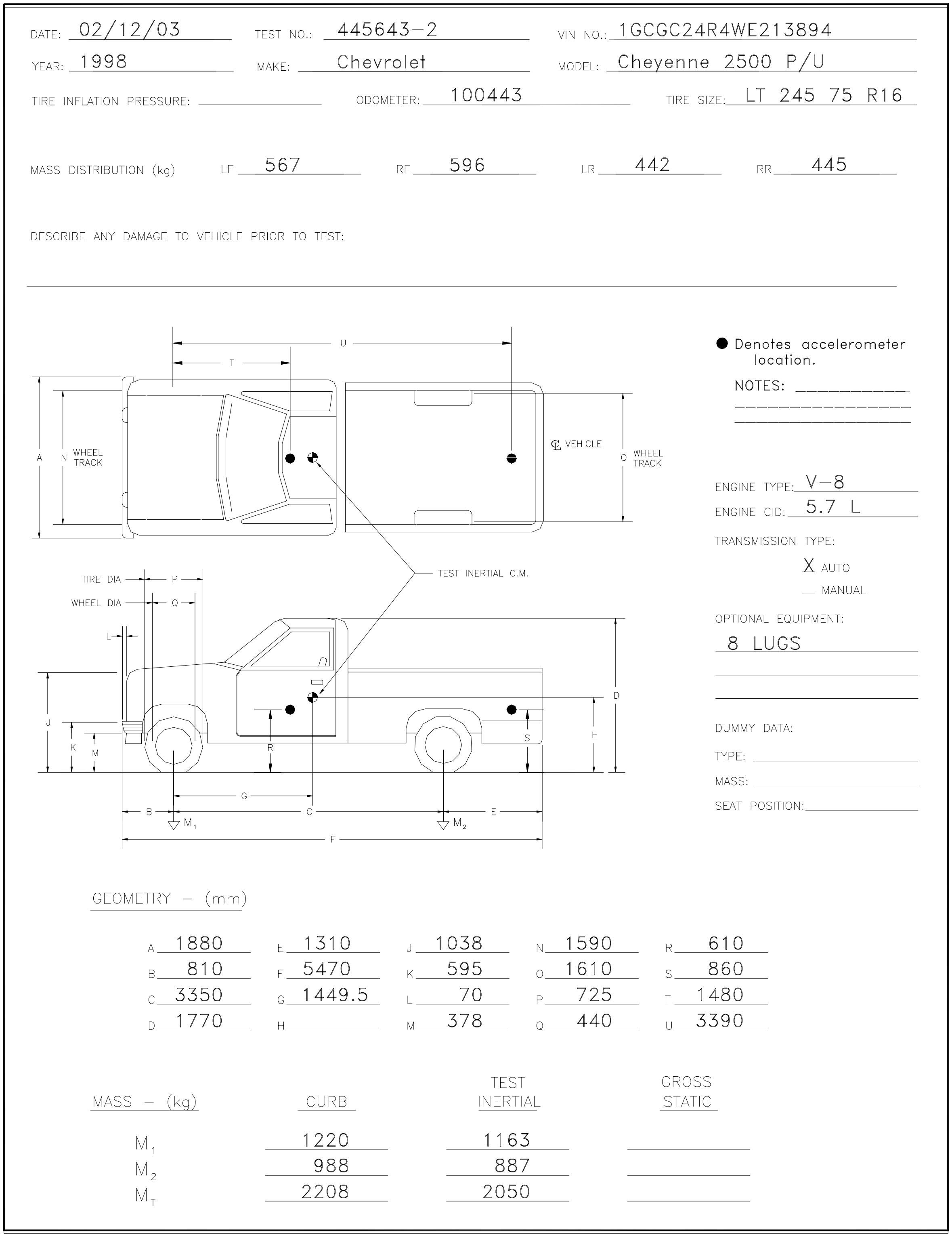






	BEFORE (mm)	AFTER (mm)
A1	872	852
A2	942	919
A3	915	913
B1	1082	1055
B2	1017	845
B3	1074	1066
C1	1373	1350
C2		
C3	1370	1374
D1	314	370
D2	159	110
D3	316	320
E1	1585	1563
E2	1592	1600
F	1465	1470
G	1465	1452
H	1250	1275
I	1243	1243
J*	1525	1440

*Lateral area across the cab from
driver's side kickpanel to passenger's side kickpanel.



DATE: 02/12/03 TEST NO.: 445643-2 VIN NO.: 1GCGC24R4WE213894

YEAR: 1998 MAKE: Chevrolet MODEL: Cheyenne 2500 P/U

TIRE INFLATION PRESSURE: ______ ODOMETER: 100443 TIRE SIZE: LT 245 75 R16

MASS DISTRIBUTION (kg) LF 567 RF 596 LR 442 RR 445

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: V-8

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

8 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1880	E	1310	J	1038	N	1590	R	610
B	810	F	5470	K	595	O	1610	S	860
C	3350	G	1449.5	L	70	P	725	T	1480
D	1770	H		M	378	Q	440	U	3390

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1220	1163	
M_2	988	887	
M_T	2208	2050	

Figure 21. Vehicle Properties for Test 445643-2.

Table 5. Exterior Crush Measurements for Test 445643-2.

VEHICLE CRUSH MEASUREMENT SHEET[1]

Complete When Applicable	
End Damage	Side Damage
Undeformed end width ________ Corner shift: A1 ________ A2 ________ End shift at frame (CDC) (check one) < 4 inches ________ ≥ 4 inches ________	Bowing: B1 _____ X1 _____ B2 _____ X2 _____ Bowing constant $\frac{X1+X2}{2}$ = _______

Note: All measurements in metric.
Note: Measure C_1 to C_6 from Driver to Passenger side in Front or Rear impacts – Rear to Front in Side Impacts.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	At front bumper	1070	450	740	450	330	200	190	125	-10	-370
2	740 mm above ground	1070	420	1120	420	300	Wheel Well		85	20	+1680

[1] Table taken from National Accident Sampling System (NASS).

*Identify the plane at which the C-measurements are taken (e.g., at bumper, above bumper, at sill, above sill, at beltline, etc.) or label adjustments (e.g., free space).

Free space value is defined as the distance between the baseline and the original body contour taken at the individual C locations. This may include the following: bumper lead, bumper taper, side protrusion, side taper, etc.
Record the value for each C-measurement and maximum crush.

**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

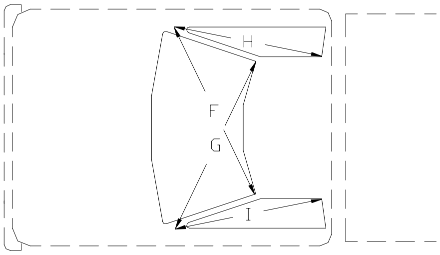
***Measure and document on the vehicle diagram the location of the maximum crush.

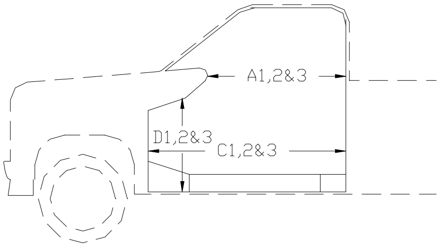
Note: Use as many lines/columns as necessary to describe each damage profile.

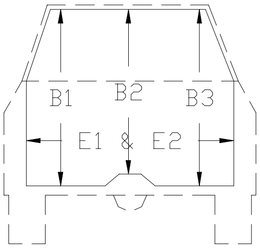
Table 6. Occupant Compartment Measurements for Test 445643-2.

Truck

Occupant Compartment Deformation







	BEFORE (mm)	AFTER (mm)
A1	872	872
A2	947	947
A3	935	935
B1	1082	1072
B2	1005	1005
B3	1074	1074
C1	1372	1370
C2		
C3	1371	1371
D1	316	305
D2	153	153
D3	304	304
E1	1591	1591
E2	1587	1587
F	1462	1462
G	1462	1462
H	1285	1285
I	1246	1246
J*	1522	1522

*Lateral area across the cab from
driver's side kickpanel to passenger's side kickpanel.

APPENDIX C. SEQUENTIAL PHOTOGRAPHS

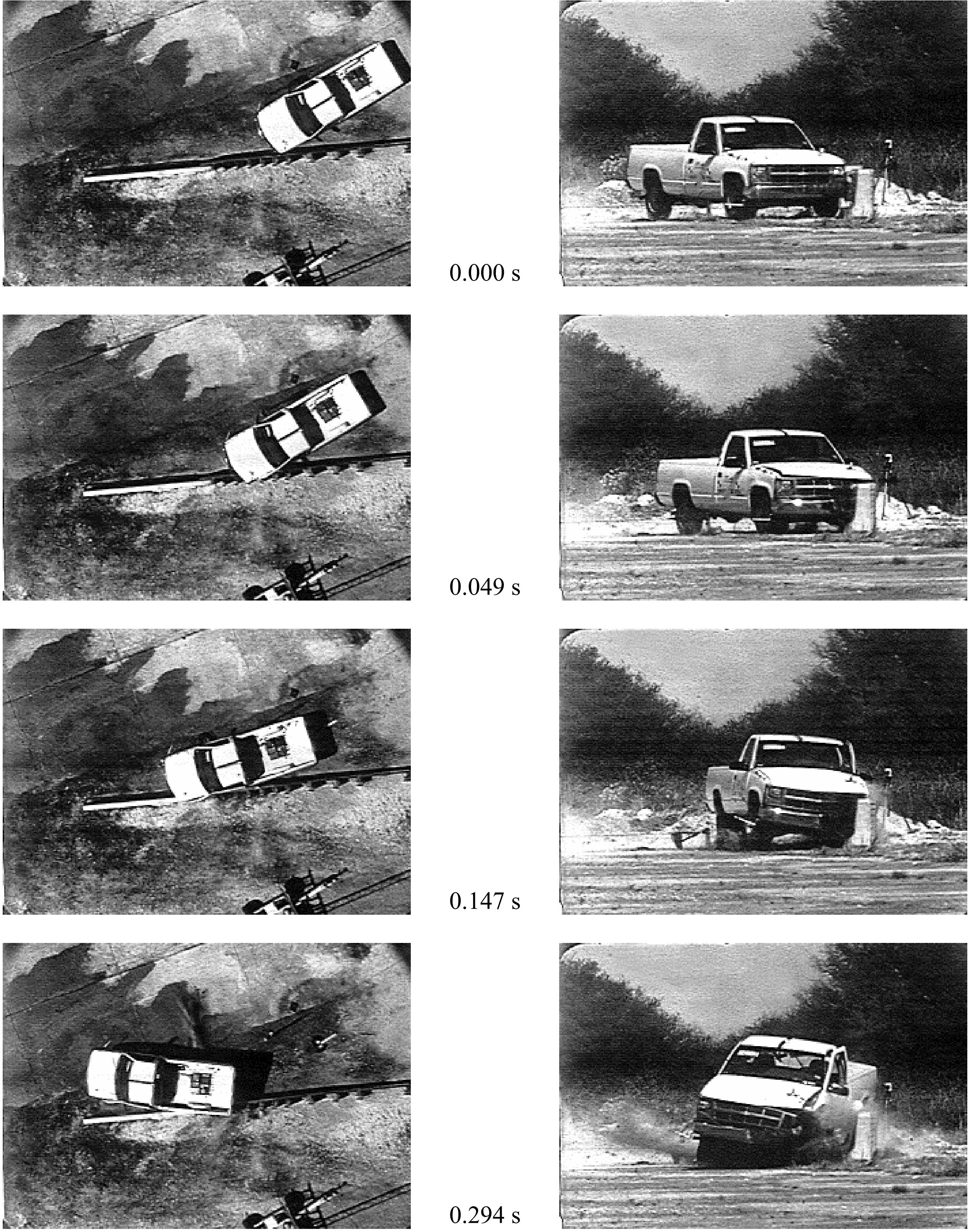
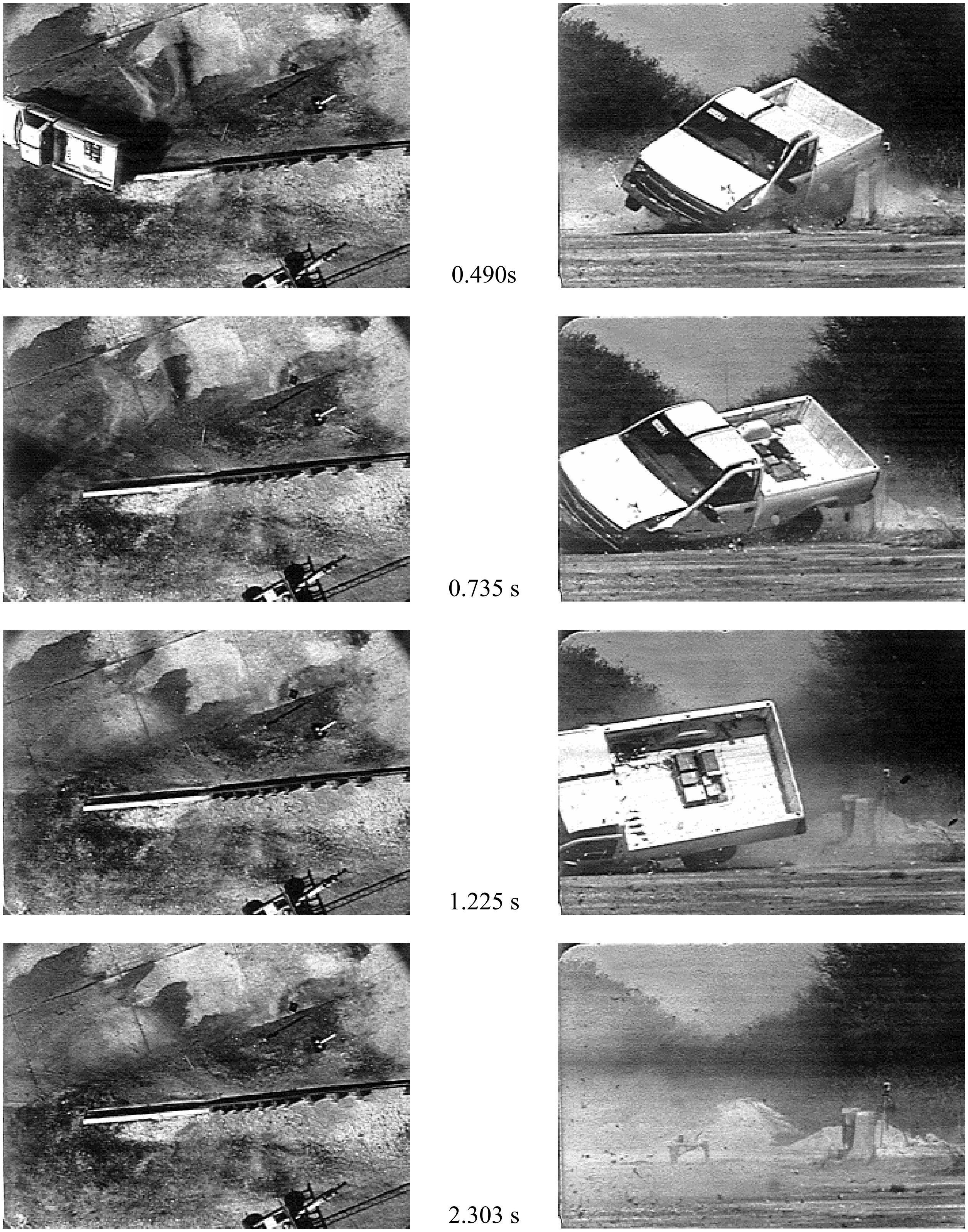


Figure 22. Sequential Photographs for Test 445643-1 (Overhead and Frontal Views).



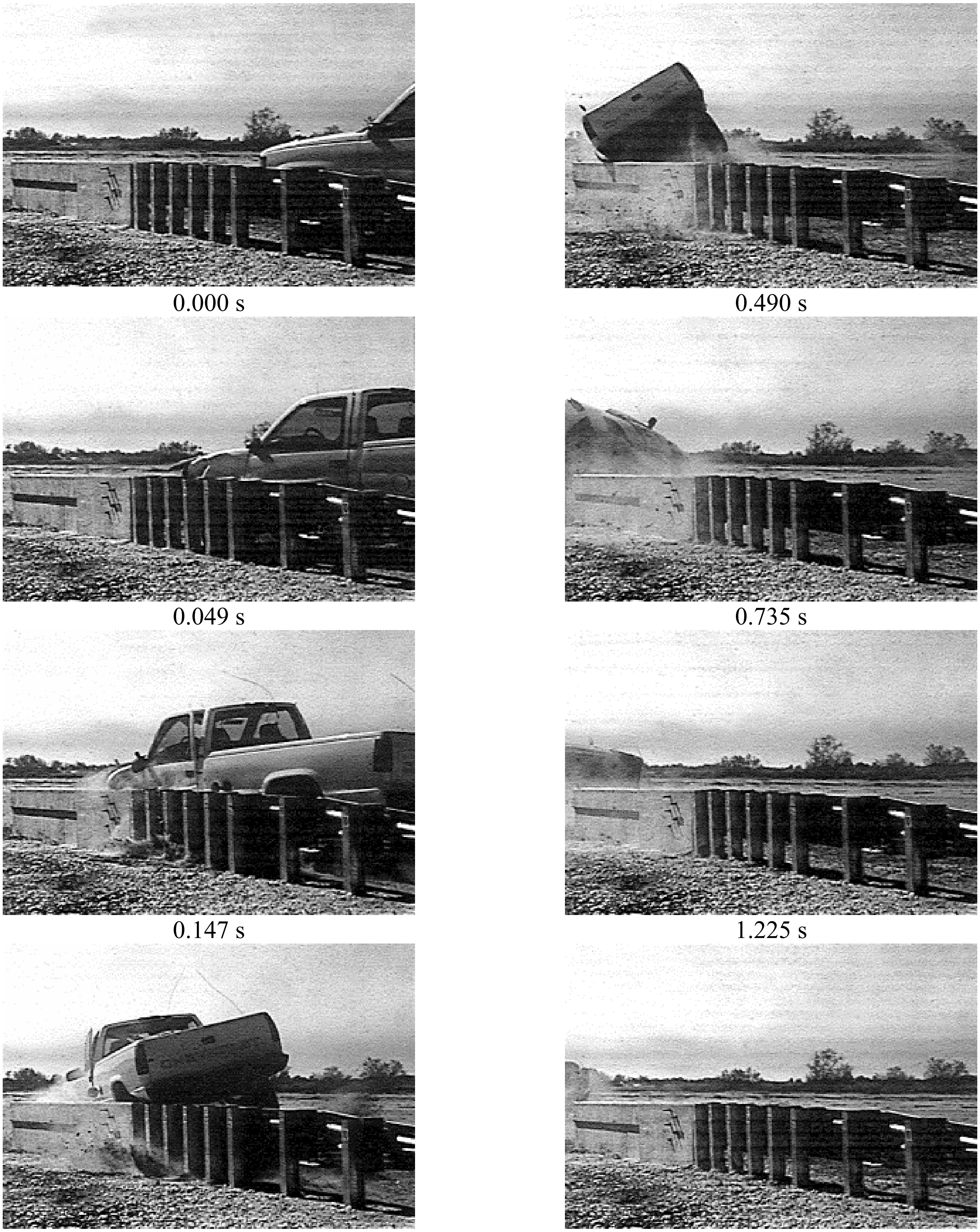
0.490s

0.735 s

1.225 s

2.303 s

Figure 22. Sequential Photographs for Test 445643-1 (Overhead and Frontal Views) (continued).



0.000 s

0.049 s

0.147 s

0.294 s

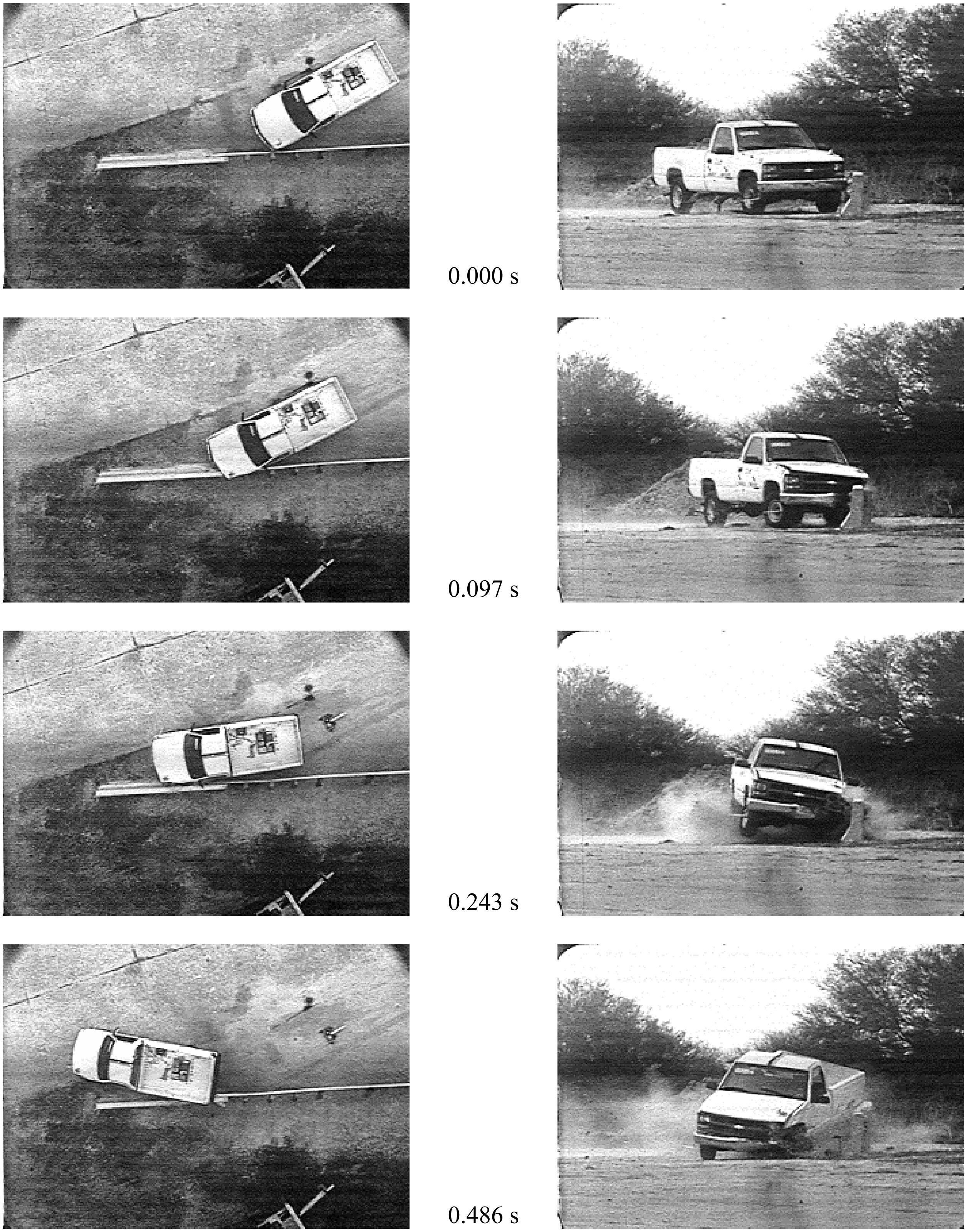
0.490 s

0.735 s

1.225 s

2.303

Figure 23. Sequential Photographs for Test 445643-1 (Rear View).



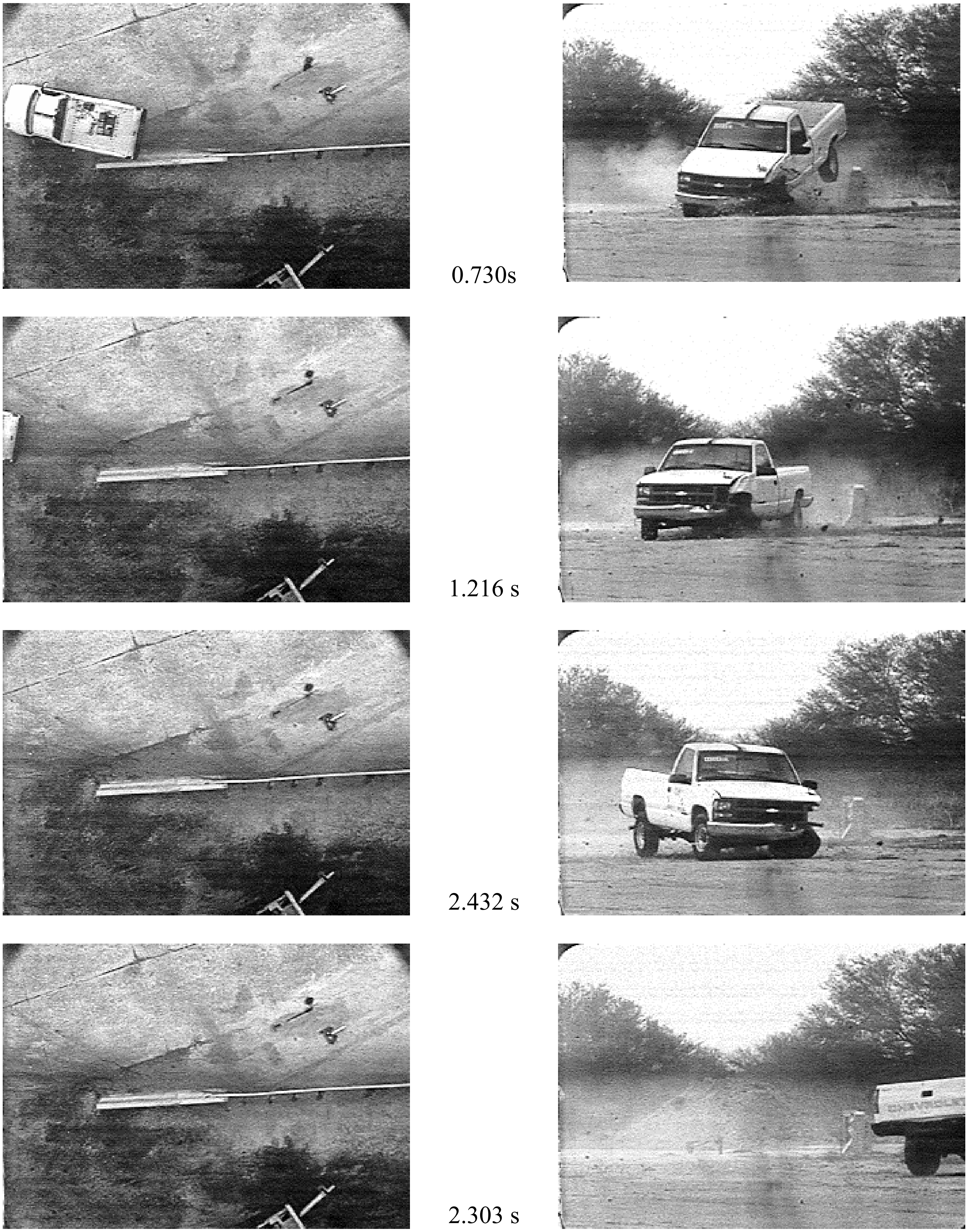
0.000 s

0.097 s

0.243 s

0.486 s

Figure 24. Sequential Photographs for Test 445643-2 (Overhead and Frontal Views).



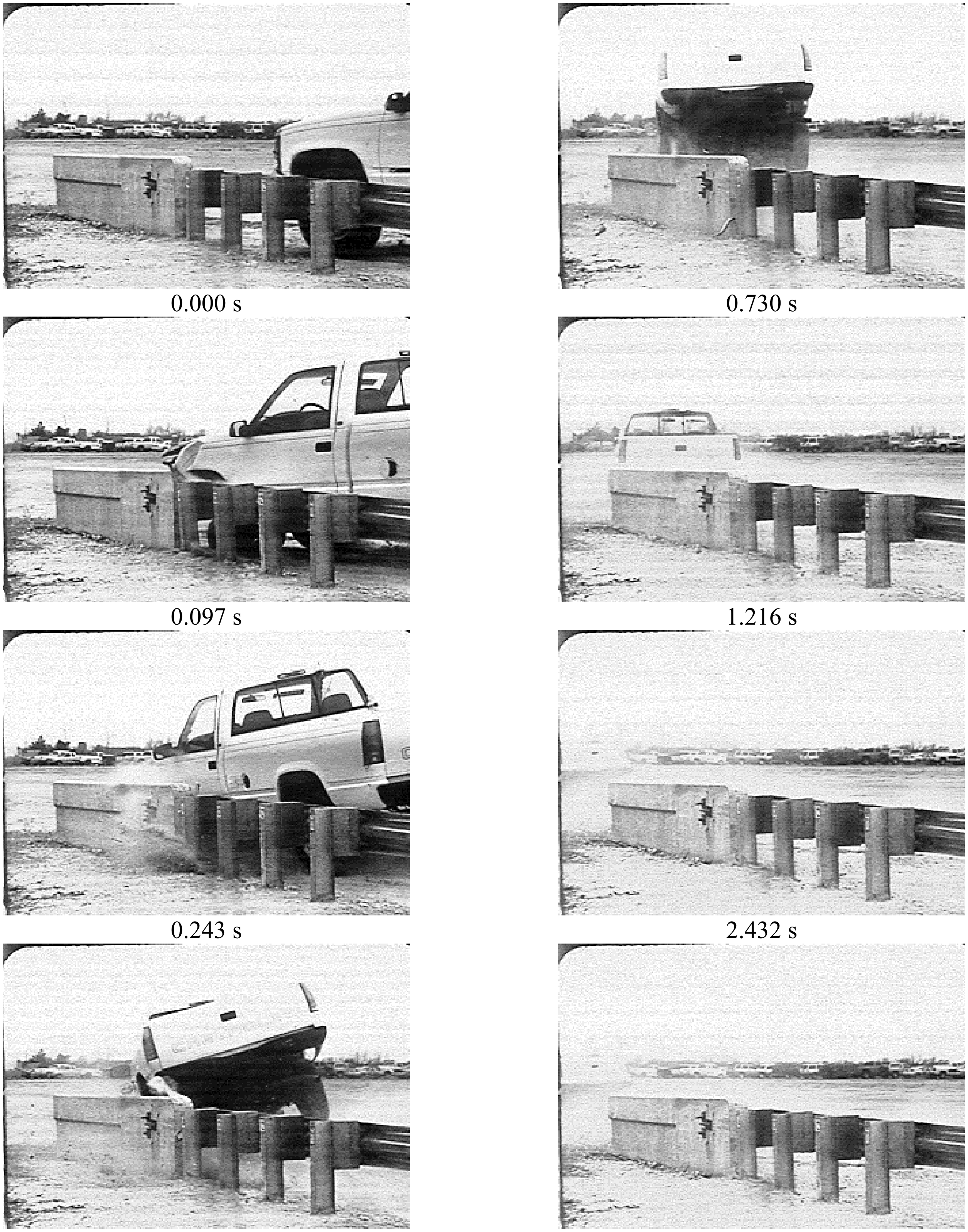
0.730s

1.216 s

2.432 s

2.303 s

Figure 24. Sequential Photographs for Test 445643-2 (Overhead and Frontal Views) (continued).



0.000 s

0.730 s

0.097 s

1.216 s

0.243 s

2.432 s

0.486 s

4.864

Figure 25. Sequential Photographs for Test 445643-2 (Rear View).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

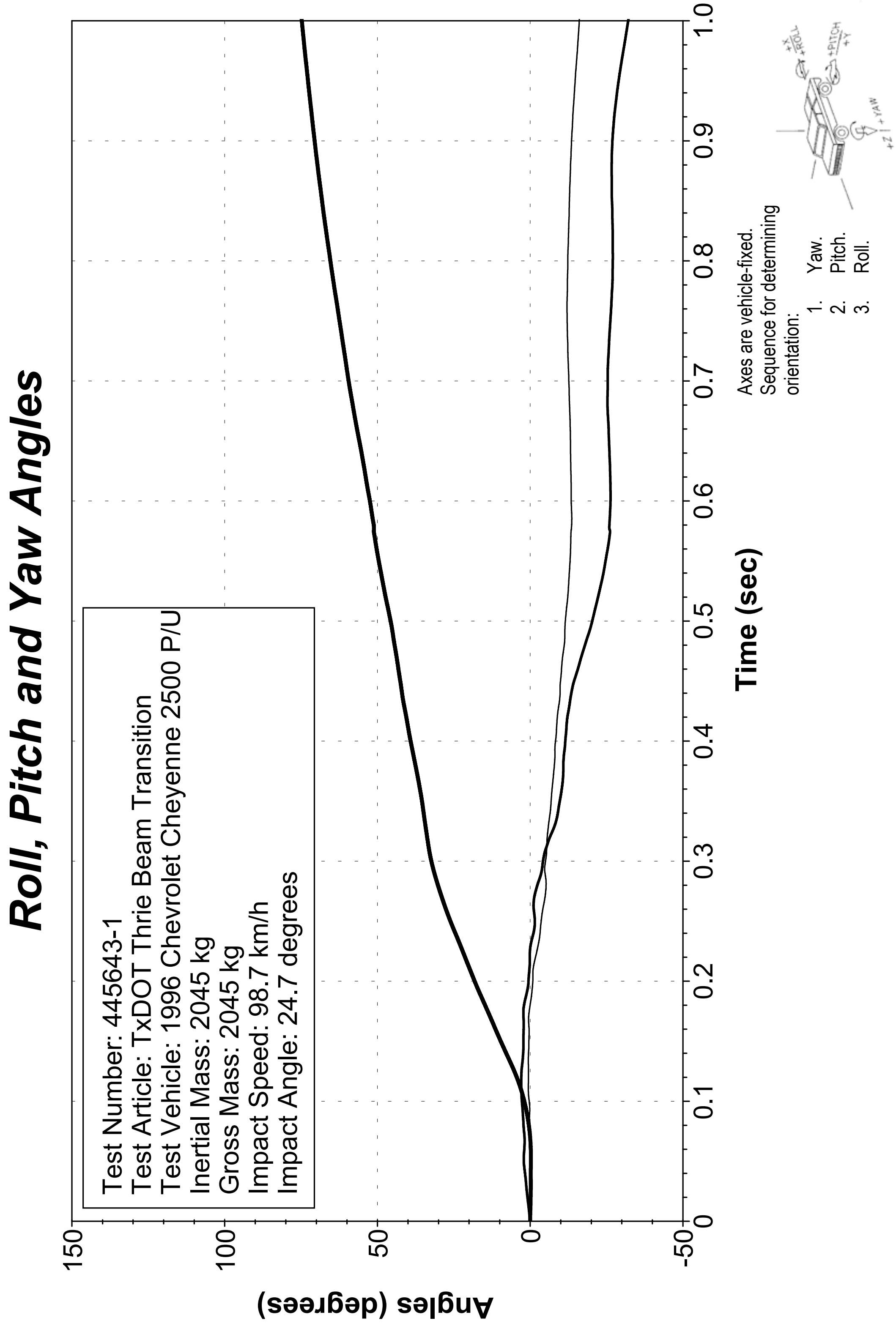


Figure 26. Vehicle Angular Displacements for Test 445643-1.

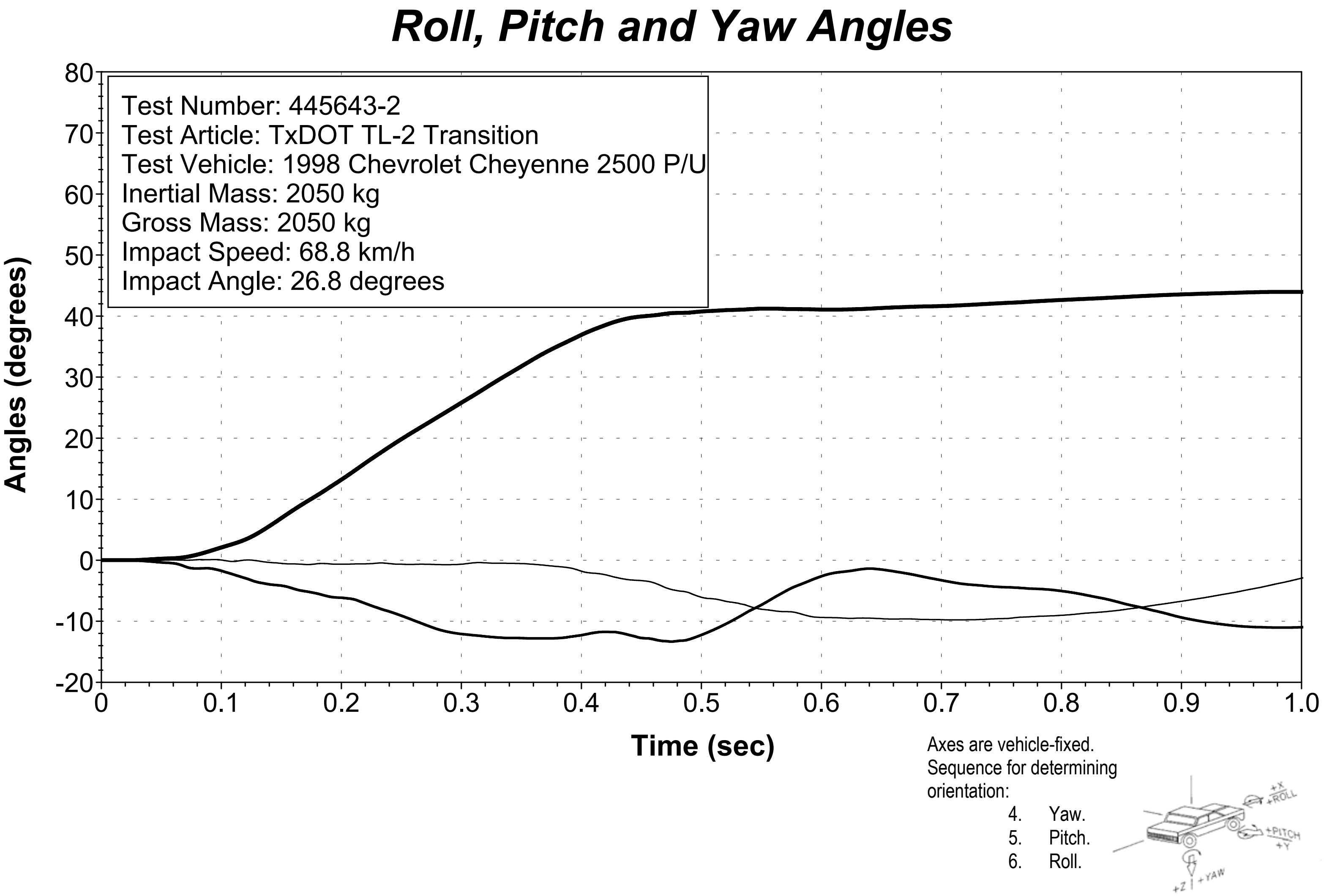


Figure 27. Vehicle Angular Displacements for Test 445643-2.

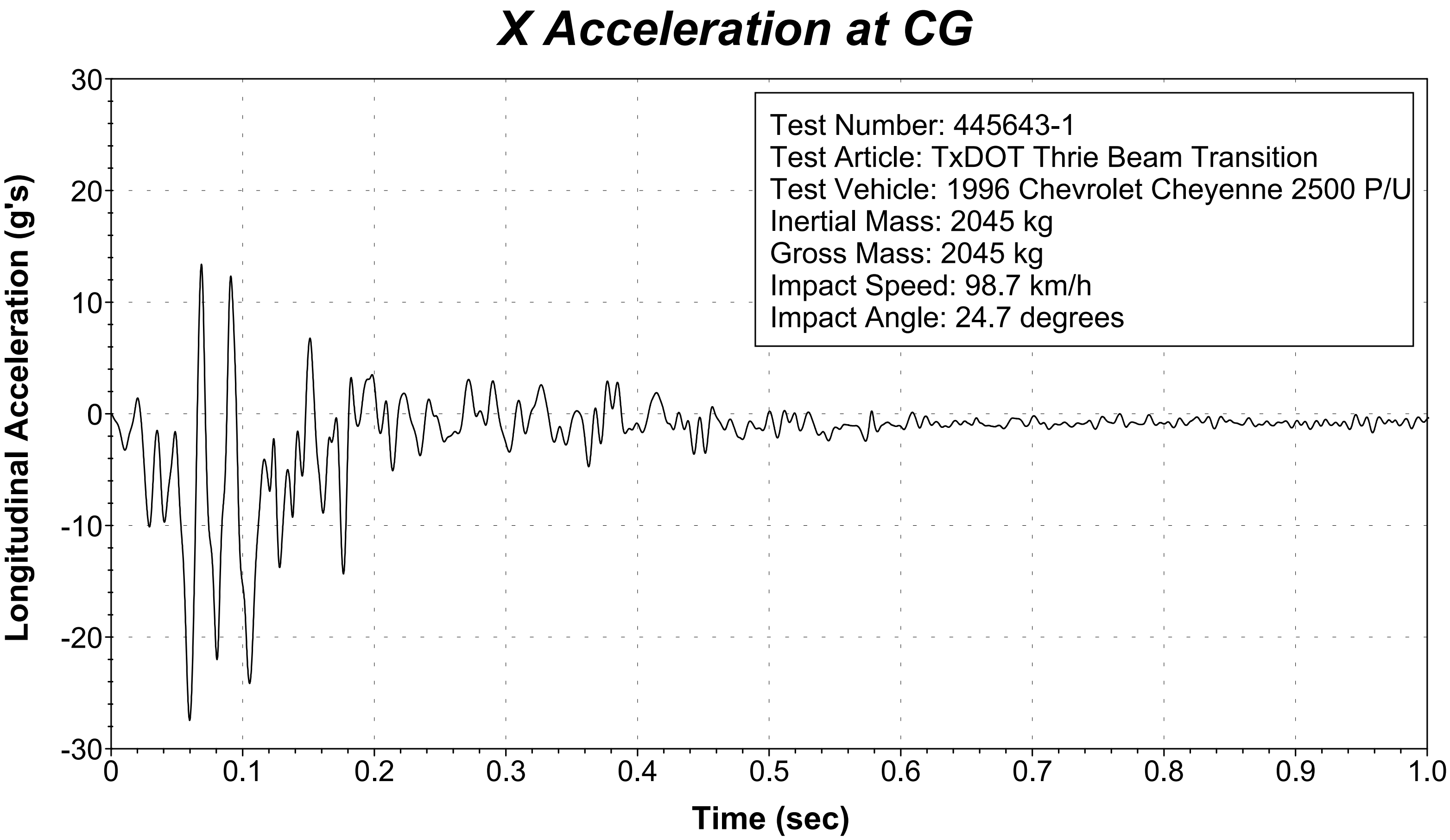


Figure 28. Vehicle Longitudinal Accelerometer Trace for Test 445643-1 (Accelerometer Located at Center of Gravity).

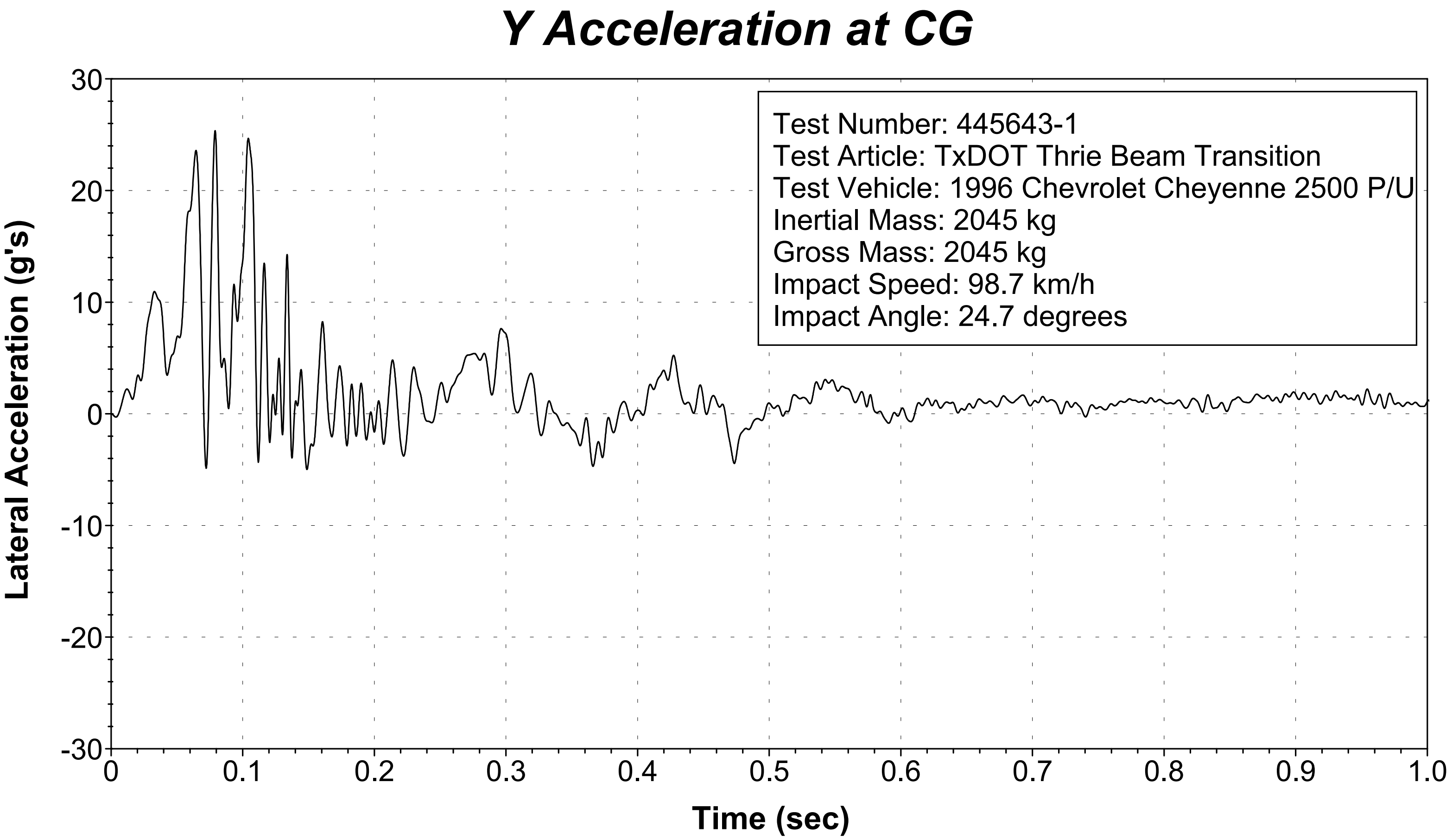


Figure 29. Vehicle Lateral Accelerometer Trace for Test 445643-1 (Accelerometer Located at Center of Gravity).

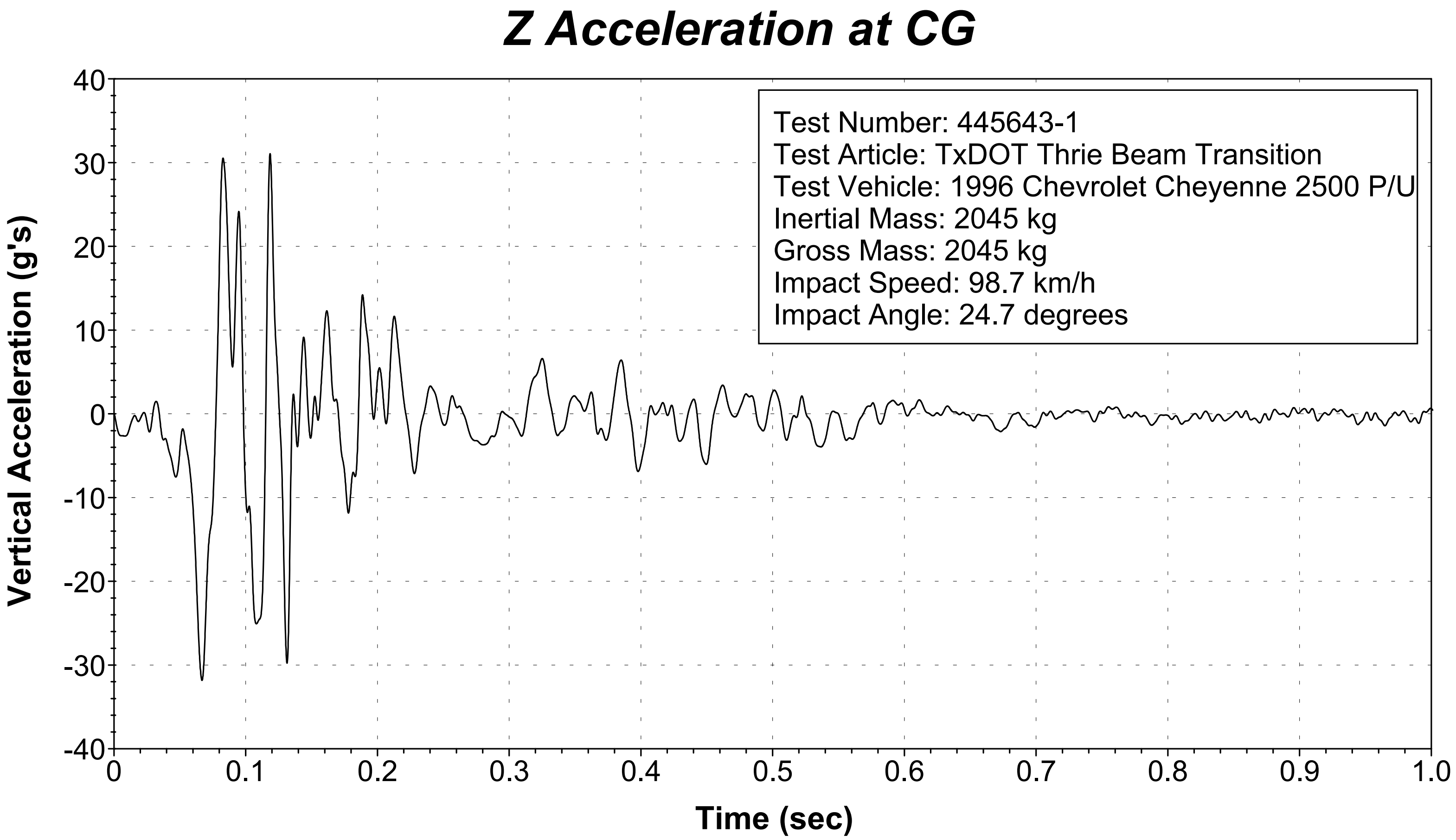


Figure 30. Vehicle Vertical Accelerometer Trace for Test 445643-1 (Accelerometer Located at Center of Gravity).

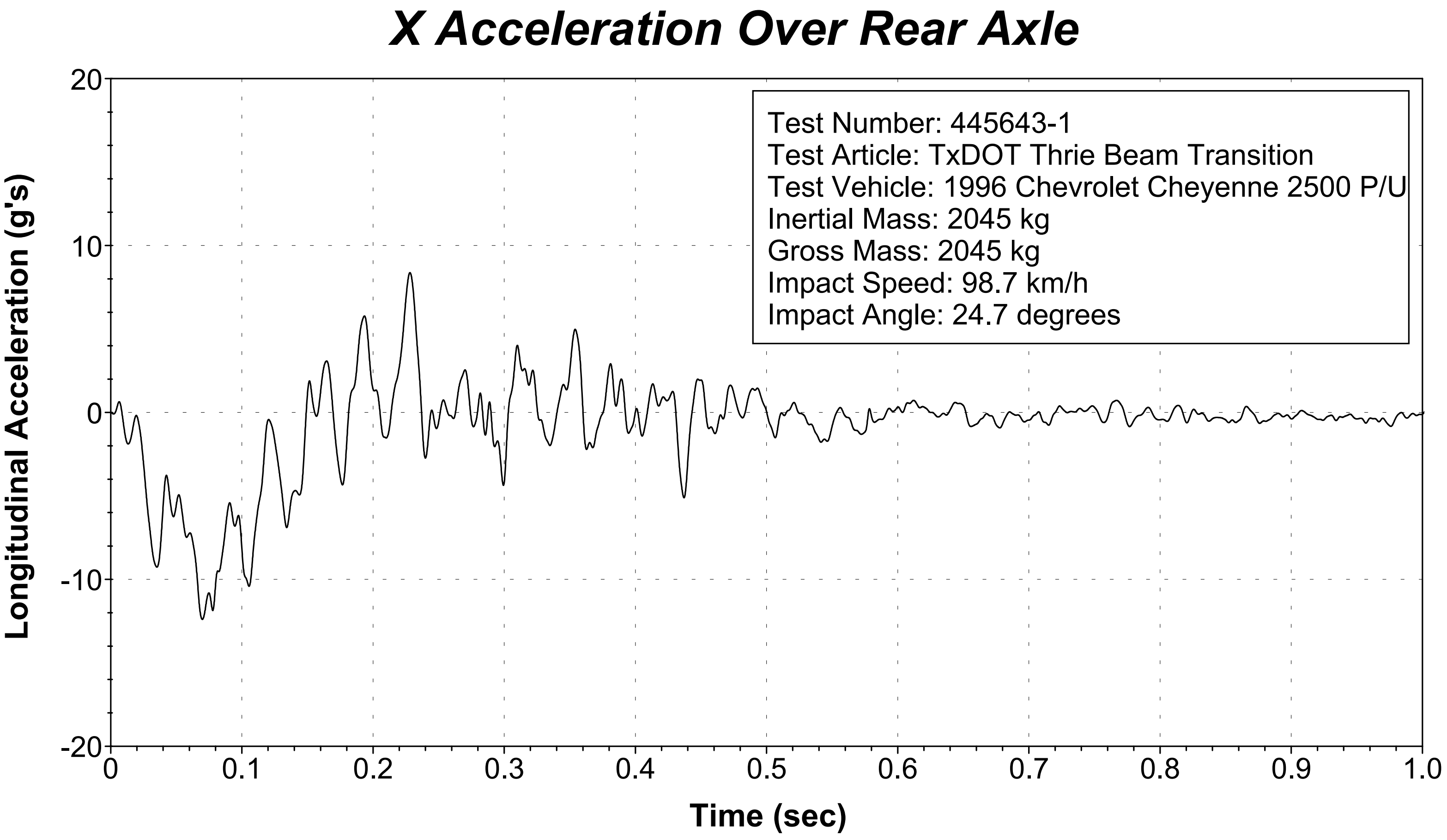


Figure 31. Vehicle Longitudinal Accelerometer Trace for Test 445643-1 (Accelerometer Located Over Rear Axle).

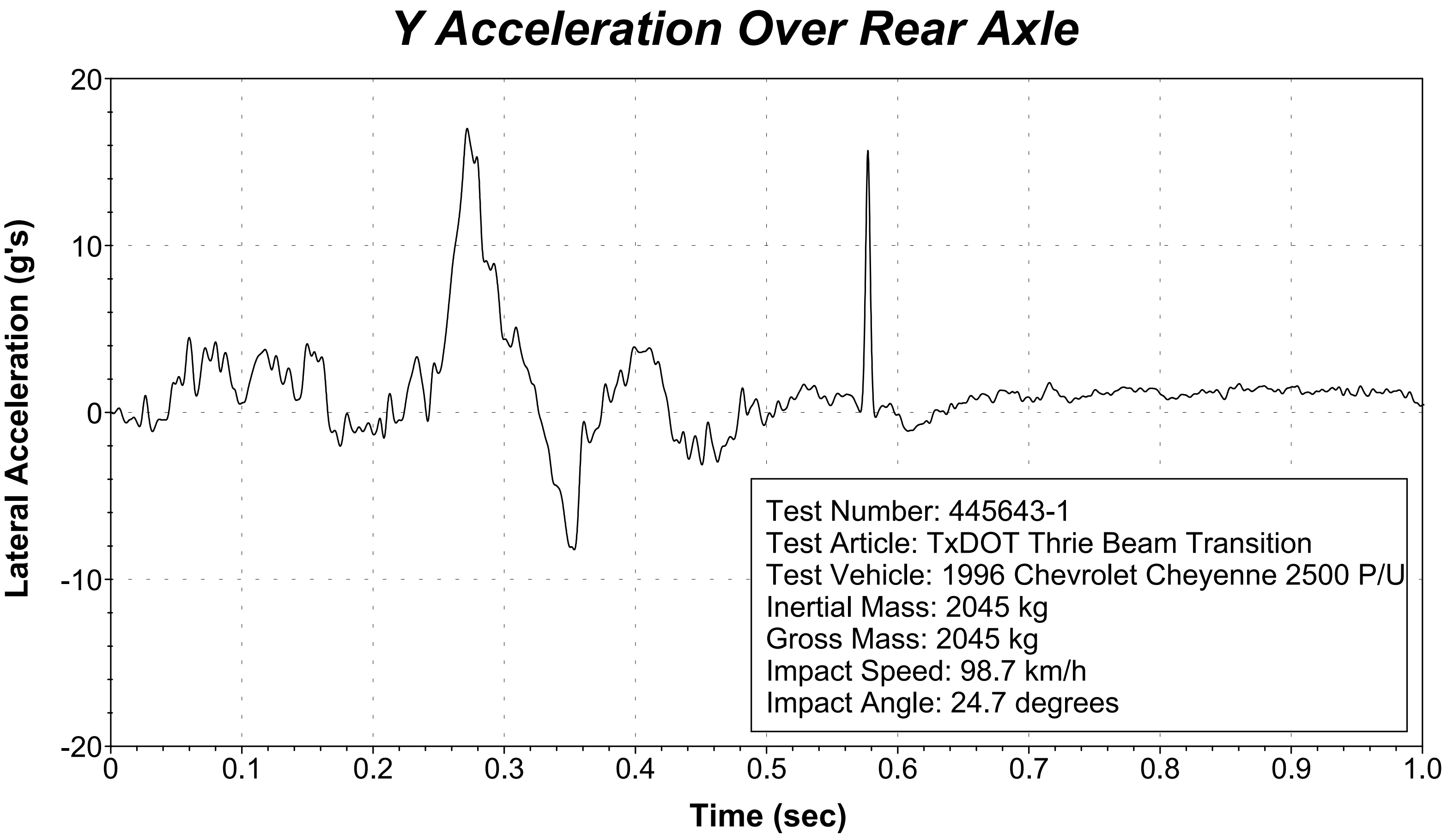


Figure 32. Vehicle Lateral Accelerometer Trace for Test 445643-1 (Accelerometer Located Over Rear Axle).

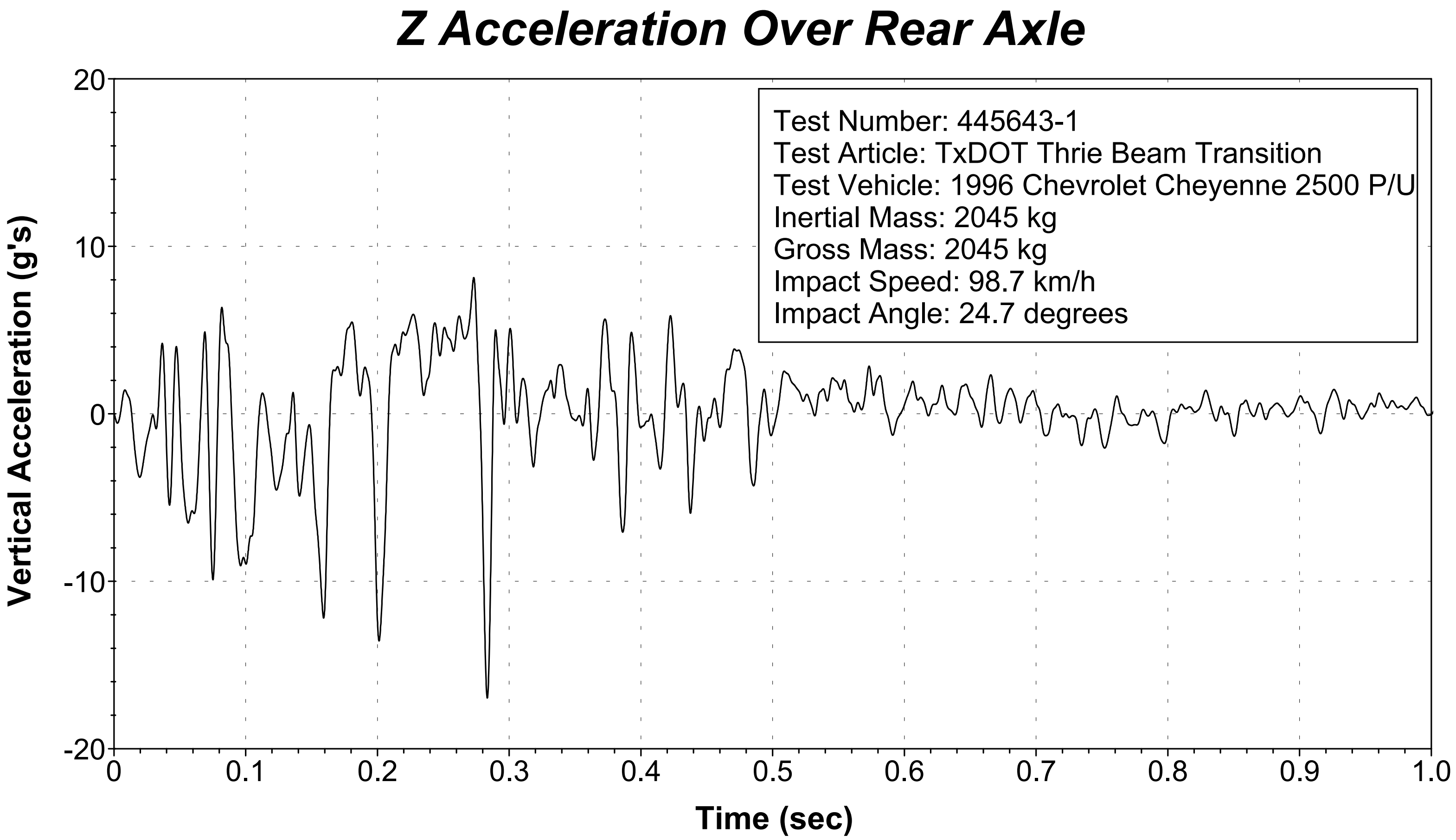


Figure 33. Vehicle Vertical Accelerometer Trace for Test 445643-1 (Accelerometer Located Over Rear Axle).

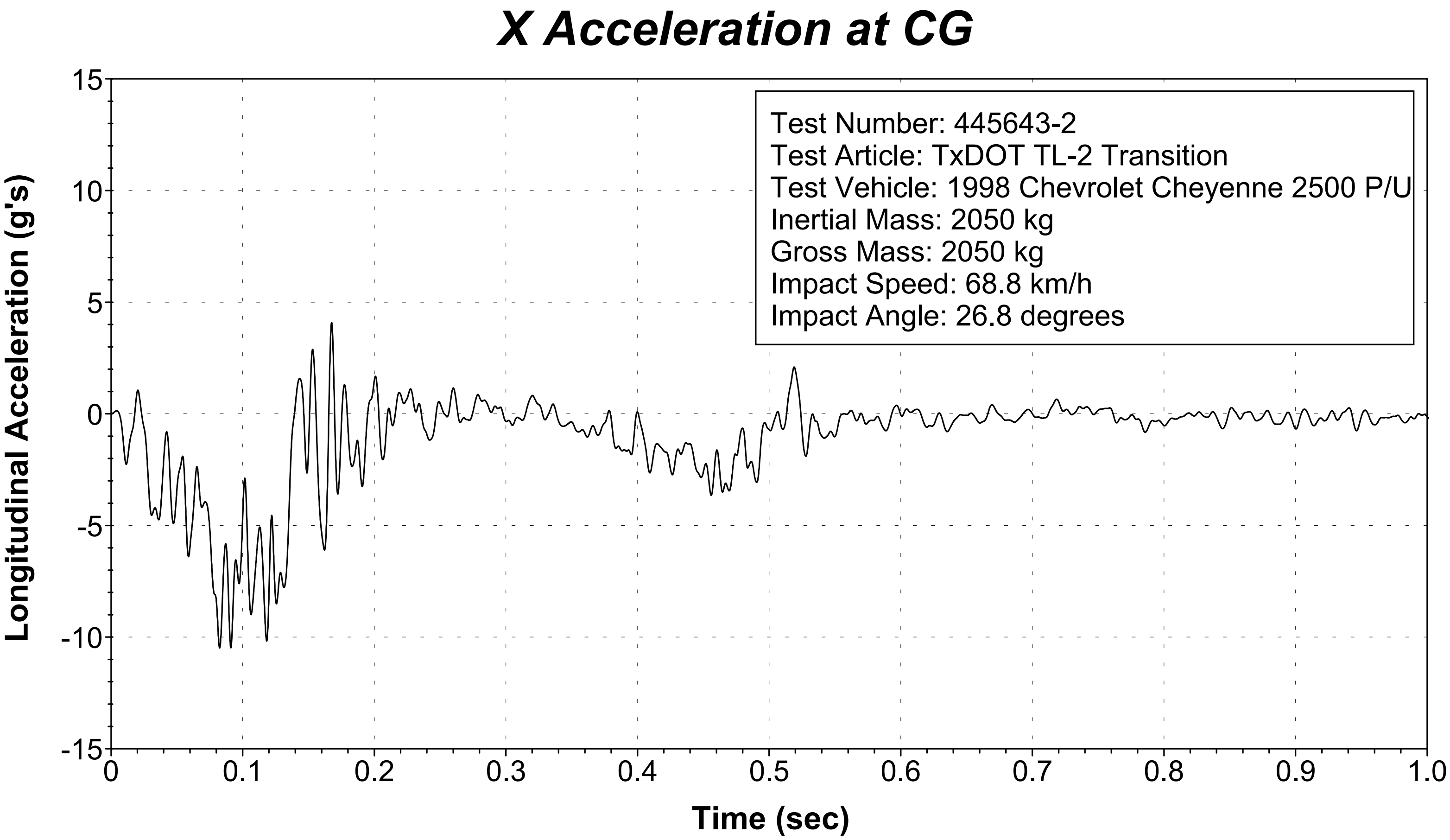


Figure 34. Vehicle Longitudinal Accelerometer Trace for Test 445643-2 (Accelerometer Located at Center of Gravity).

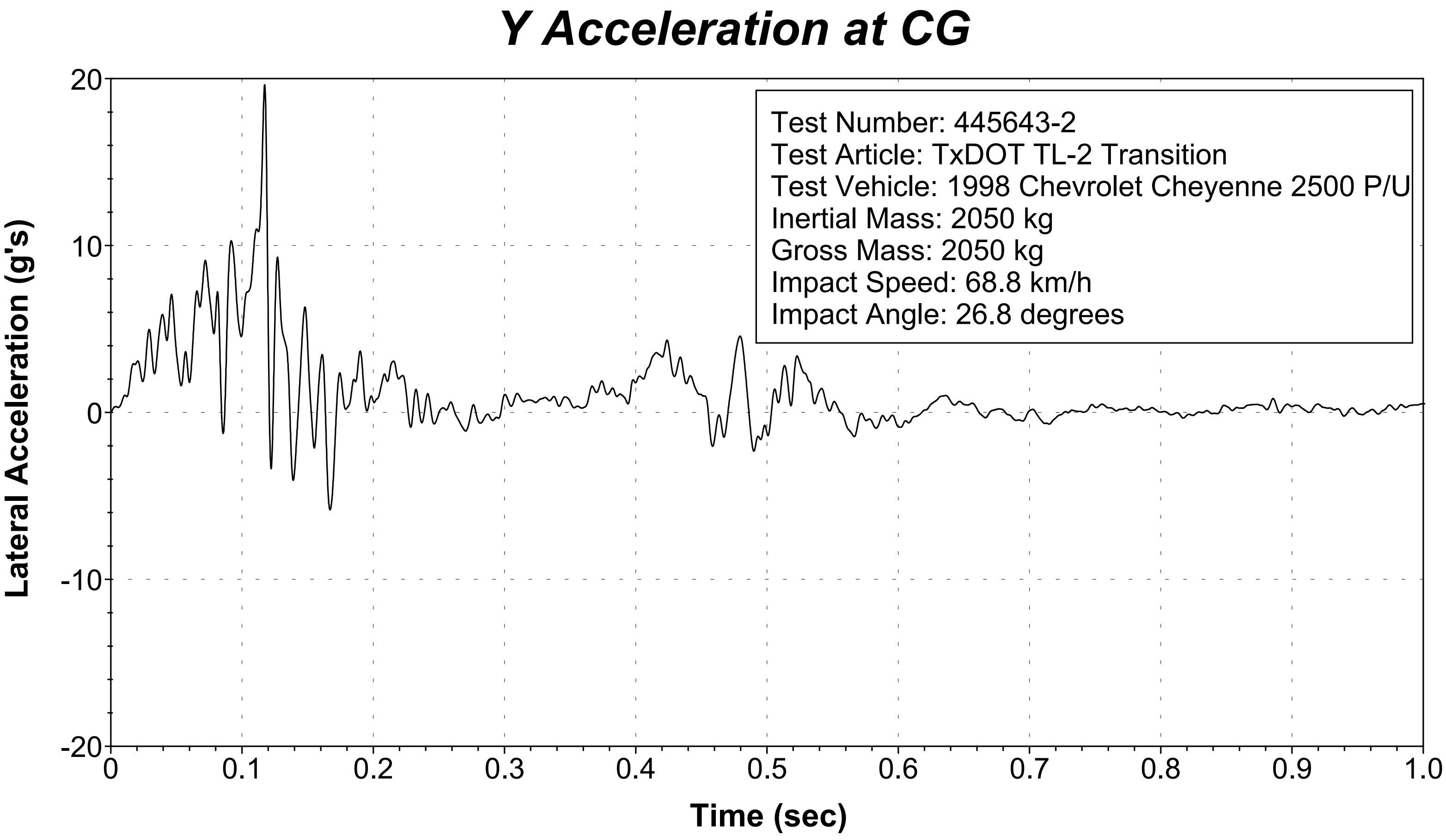


Figure 35. Vehicle Lateral Accelerometer Trace for Test 445643-2 (Accelerometer Located at Center of Gravity).

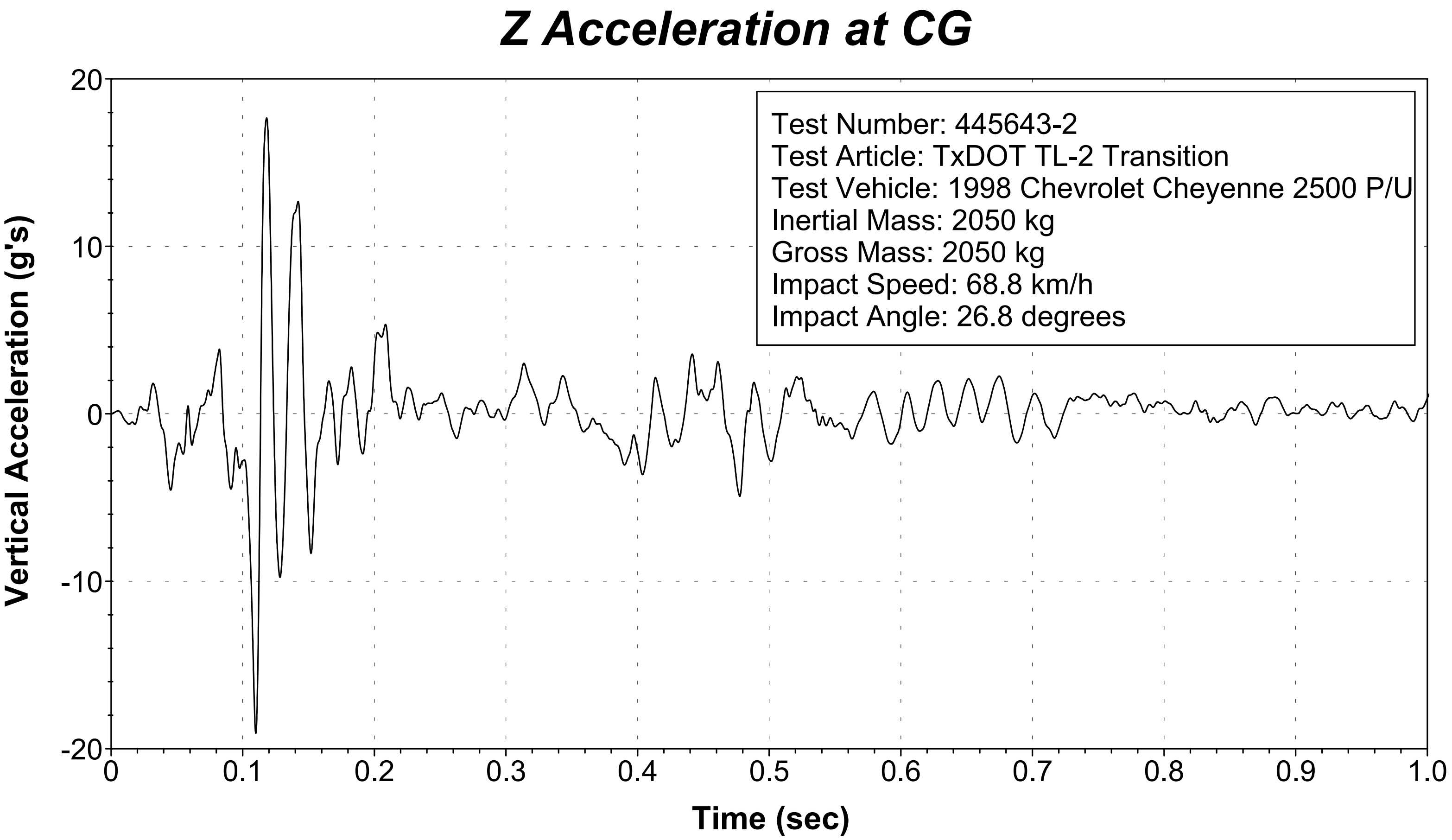


Figure 36. Vehicle Vertical Accelerometer Trace for Test 445643-2 (Accelerometer Located at Center of Gravity).

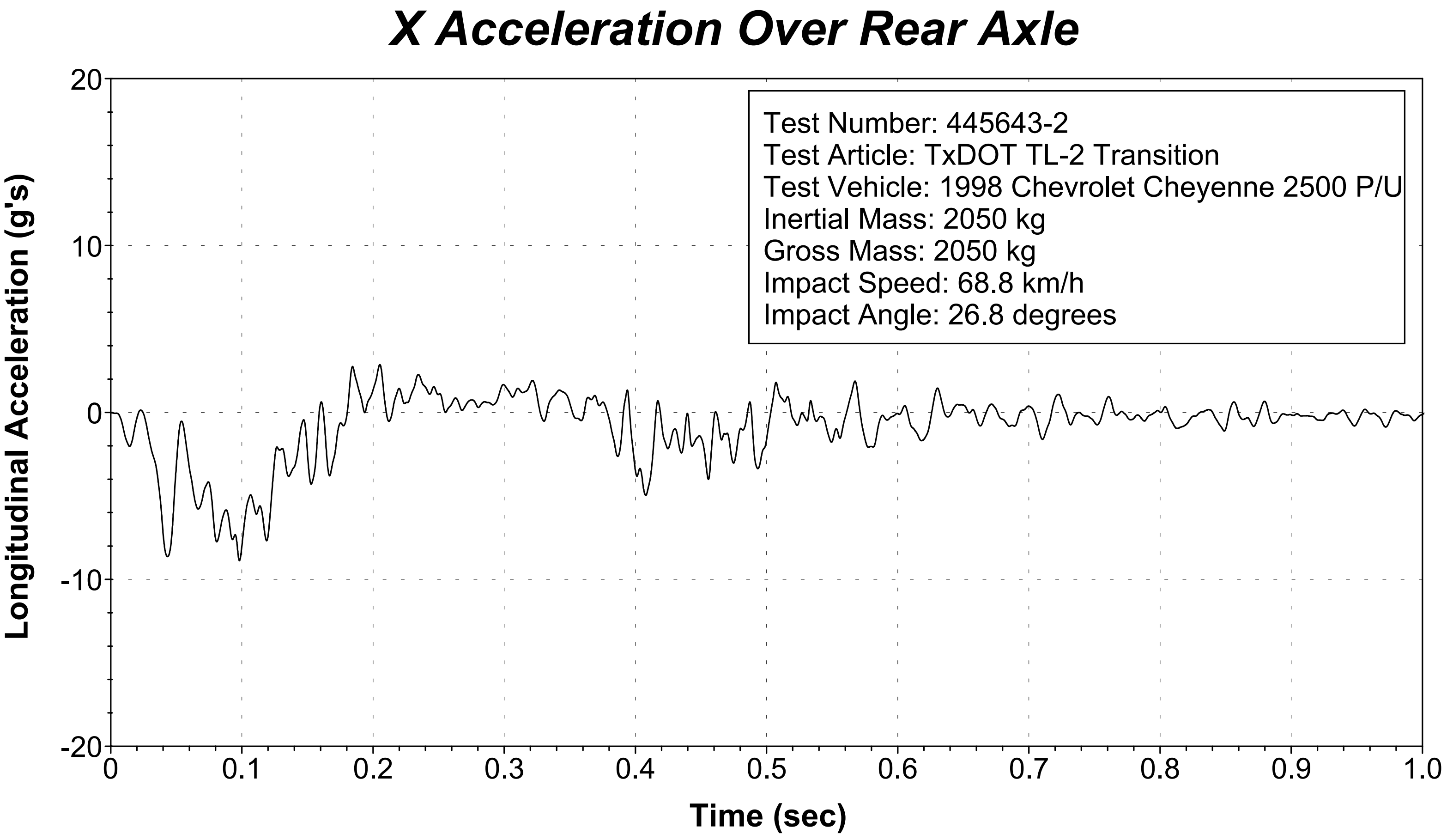


Figure 37. Vehicle Longitudinal Accelerometer Trace for Test 445643-2 (Accelerometer Located Over Rear Axle).

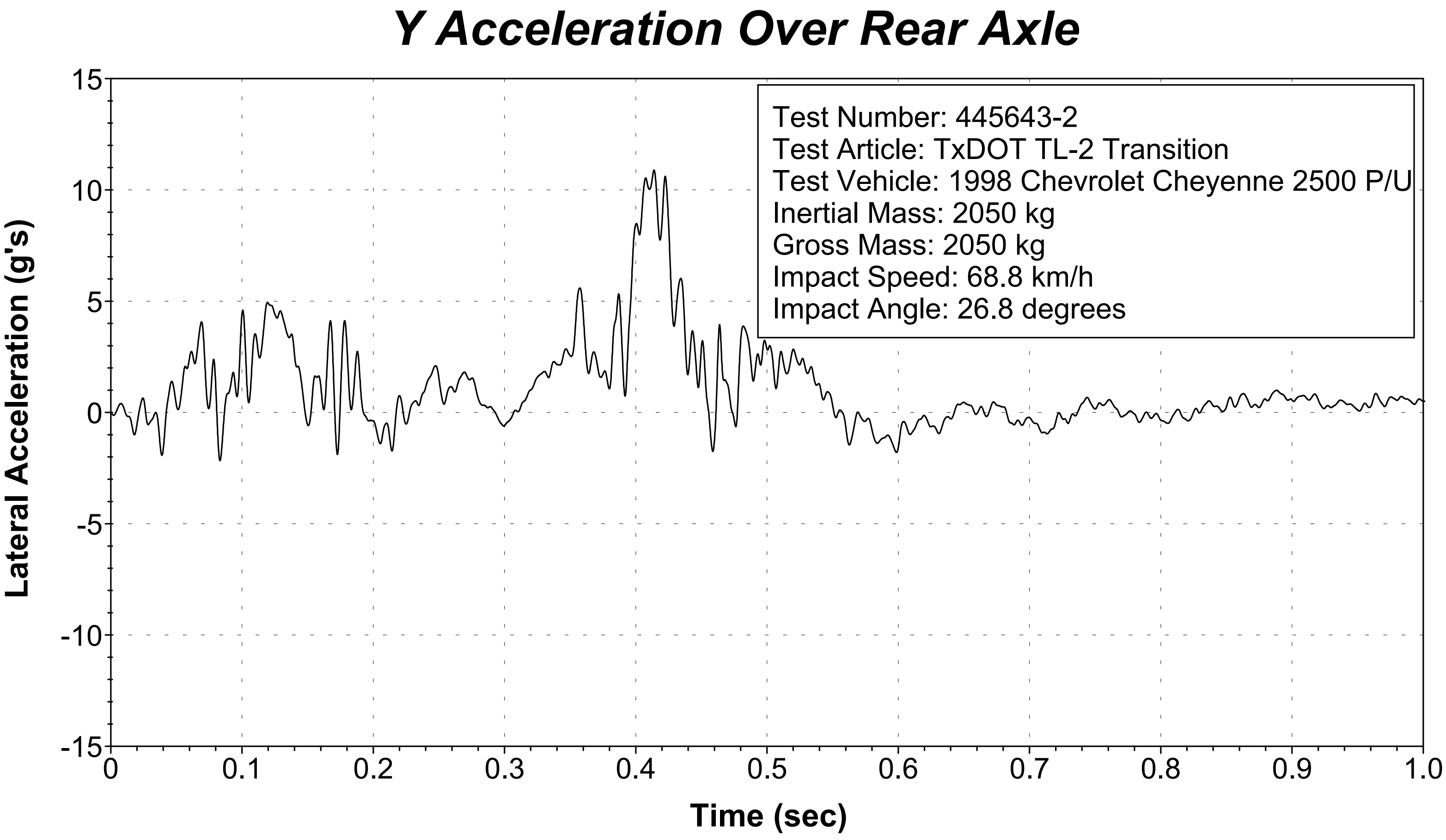


Figure 38. Vehicle Lateral Accelerometer Trace for Test 445643-2 (Accelerometer Located Over Rear Axle).

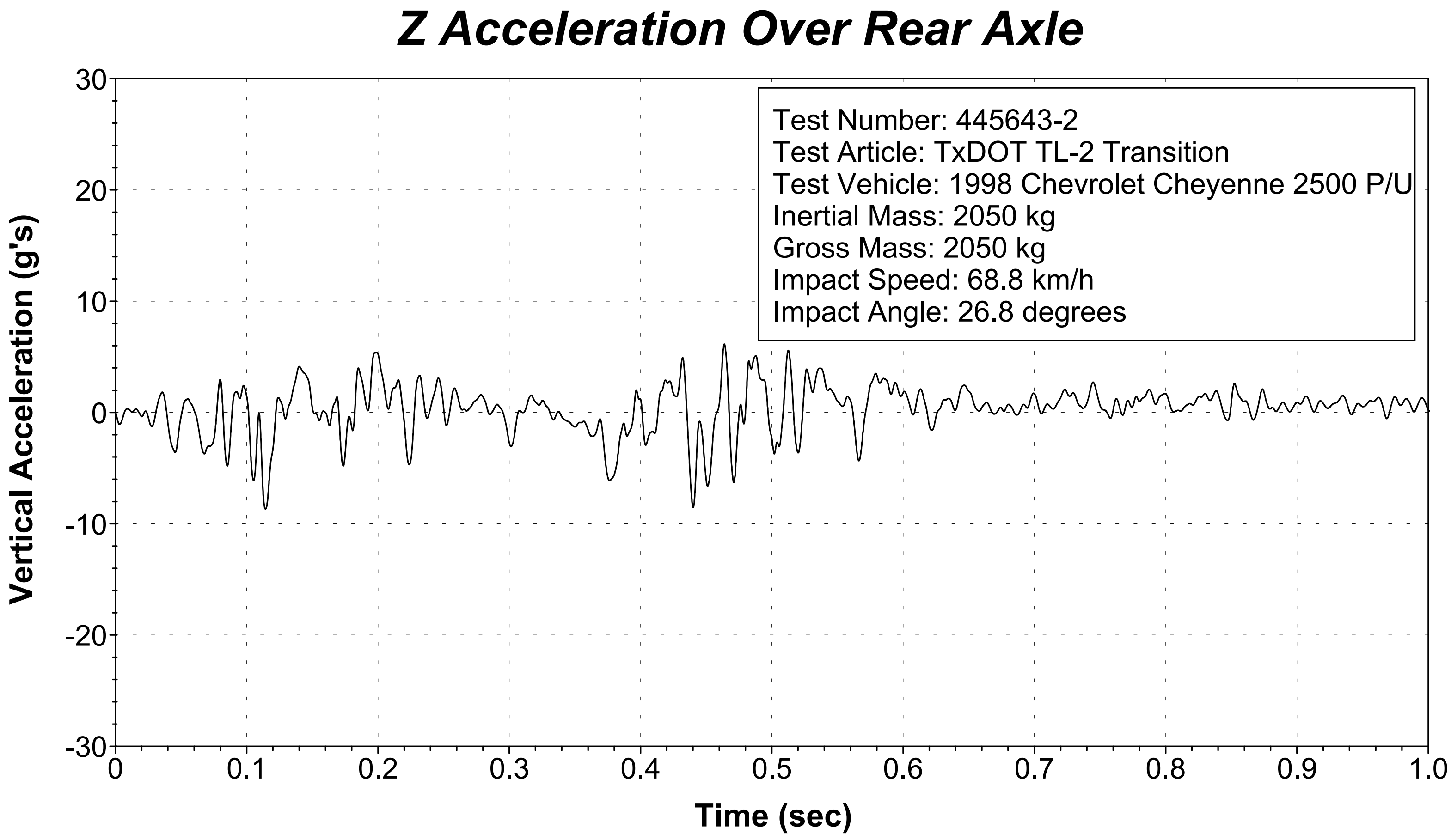


Figure 39. Vehicle Vertical Accelerometer Trace for Test 445643-2 (Accelerometer Located Over Rear Axle).