Texas Transportation Institute

NCHRP REPORT 350 TEST 3-11 OF THE NEW YORK DOT PORTABLE CONCRETE BARRIER WITH I-BEAM CONNECTION (RETEST)

by

Roger P. Bligh, P.E.
Assistant Research Engineer

Wanda L. Menges
Associate Research Specialist

and

Sandra K. Sanders
Research Associate

Contract No. DTFH61-97-C-00064
Project No. 473220-14

Sponsored by
U.S. Department of Transportation
Federal Highway Administration

July 2001

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A & M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS 77843

DISCLAIMER

KEY WORDS

Portable Concrete Barriers, PCB, Concrete Median Barriers, CMB, Work Zone Devices, Traffic Control Devices, Crash Testing, Roadside Safety

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle NCHRP REPORT 350 TEST 3-11 OF THE NEW YORK DOT PORTABLE CONCRETE BARRIER WITH I-BEAM CONNECTION (RETEST)		5. Report Date July 2001
		6. Performing Organization Code
7. Author(s) Roger P. Bligh, Wanda L. Menges and Sandra K. Sanders		8. Performing Organization Report No. 473220-14
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFH61-97-C-00064
12. Sponsoring Agency Name and Address Office of Safety and Traffic Operations Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Test Report October 1997-July 2001
		14. Sponsoring Agency Code

15. Supplementary Notes
Research Study Title: Work Zone Appurtenances Tested to NCHRP 350
Contracting Officer's Technical Representative (COTR): Charles F. McDevitt

16. Abstract

In previous testing, *NCHRP Report 350* test 3-11 was performed on the New York Department of Transportation (NYDOT) portable concrete barrier (PCB). In this test, the rear of the 2000-kg pickup truck rode up the face of the barrier, extended over the barrier and then rolled over along the top of the barrier. The joints on both ends of the barrier segment immediately downstream of the point of impact failed, allowing the segment to overturn on its side. This barrier segment came to rest with one end projecting 5.2 m behind the installation. A third joint immediately upstream of the point of impact also partially failed.

Inspection and analysis of the failed connections indicated that the tested barrier had only 24 percent of its intended connection capacity due to improper weld length, size, and penetration. It was determined that a PCB properly fabricated according to NYDOT standards and specifications should have adequate strength to perform satisfactorily and meet the evaluation criteria set forth in *NCHRP Report 350*. Thus, a recommendation was made to fabricate new barrier segments with the proper welding details and re-run *NCHRP Report 350* test 3-11 with the new barrier segments.

During this repeat of *NCHRP Report 350* test 3-11 on the NYDOT PCB, the welds held as intended and the barrier contained and redirected the 2000-kg pickup truck. The NYDOT PCB met the required criteria specified for *NCHRP Report 350* test 3-11.

17. Key Words	18. Distribution Statement
Portable Concrete Barriers, PCB, Concrete Median Barriers, CMB, Work Zone Devices, Traffic Control Devices, Crash Testing, Roadside Safety	No restrictions. This document is available to the public through the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square	mm^2
ft^2	square feet	0.093	millimeters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	square meters	ha
mi^2	square miles	2.59	hectares	km^2
			square kilometers	
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply by	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C+32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

BACKGROUND

Safety in work zones is a major concern since it is not always possible to maintain a level of safety comparable to that of a normal highway not under construction. Proper traffic control and crashworthy work zone barriers are critical elements to providing safety for both motorists and workers. Thus, the Federal Highway Administration (FHWA) and the Manual on Uniform on Uniform Traffic Control Devices (MUTCD) require that work zone traffic control devices be crashworthy.[1]

A wide variety of traffic control devices and roadside appurtenances are currently used in work zones. These include portable concrete barriers, temporary sign supports, and Types I, II, and III barricades. Many of these devices and appurtenances have not been crash tested and evaluated in accordance with the recommended procedures set forth in National Cooperative Highway Research Program (NCHRP) *Report 350*.[2] A crash test program was, therefore, funded to test selected work zone appurtenances to evaluate their crashworthiness.

Eleven States contributed funds to State Planning and Research (SP&R) Pooled Fund Study 2-188, "Crash Tested Safety Appurtenances for Work Zones." A list of appurtenances to be crash tested and evaluated was identified and prioritized by representatives from the participating States. Included in the list of work zone appurtenances selected for evaluation was the New York Department of Transportation (NYDOT) portable concrete barrier (PCB).

PROBLEM STATEMENT

In previous testing, *NCHRP Report 350* test 3-11 was performed on the NYDOT PCB.[3] In this test, the rear of the 2000-kg pickup truck rode up the face of the barrier, extended over the barrier and then rolled over along the top of the barrier. The joints on both ends of the barrier segment immediately downstream of the point of impact failed, allowing the segment to overturn on its side. This barrier segment came to rest with one end projecting 5.2 m behind the installation. A third joint immediately upstream of the point of impact also partially failed.

Inspection and analysis of the failed connections indicated that the tested barrier had only 24 percent of its intended connection capacity due to improper weld length, size, and penetration. It was determined that a PCB properly fabricated according to NYDOT standards and specifications should have adequate strength to perform satisfactorily and meet the evaluation criteria set forth in *NCHRP Report 350*. Thus, a recommendation was made to fabricate new barrier segments with the proper welding details and re-run *NCHRP Report 350* test 3-11 with the new barrier segments.

OBJECTIVES/SCOPE OF RESEARCH

The overall objective of this study, as delineated in the Statement of Work, is "To design, test, and develop work zone appurtenances for use by the States." The scope of the study, as delineated in the Statement of Work, is as follows:

> *This requirement consists of conducting full-scale tests of work zone appurtenances, designing, and redesigning these appurtenances as necessary to improve their performance, preparing detailed design drawings and .... This contract will provide crash tested and evaluated work zone appurtenances for use by the States.*

Reported herein as part of this effort are the details and results of a full-scale crash test performed on newly constructed New York Department of Transportation (NYDOT) portable concrete barrier (PCB) segments with I-beam connectors. The crash test conditions conformed to *NCHRP Report 350* test designation 3-11 which involves a 2000-kg pickup truck impacting the critical impact point (CIP) of the PCB at a nominal speed and angle of 100 km/h and 25 degrees, respectively. The "Technical Discussion" section contains descriptions of the test facility, details of the NYDOT PCB with I-beam connection, the *NCHRP Report 350* test matrix for longitudinal barriers, *NCHRP Report 350* criteria specified for evaluation of this test, and the crash test results and assessment. The "Conclusions and Recommendations" section summarizes the results of testing and conclusions derived from the testing.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare complex of research and training facilities situated 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 placement of the New York DOT PCB with I-beam connection was along a concrete apron which was originally used for parking military aircraft. The apron consists of 3.8 m by 4.6 m blocks of unreinforced jointed concrete pavement (shown in the adjacent photo) nominally 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.

Test Article – Design and Construction

The test article is an 810-mm high New Jersey safety shaped portable concrete barrier (PCB) used by the New York Department of Transportation (NYDOT). TTI received a standard drawing sheet from NYDOT entitled, "Temporary Concrete Barrier." The drawing number is M619-3R1 and it is not dated. This drawing, shown as figure 1, provides details for constructing the PCB segments and their connection hardware. Further details are provided below.

In accordance with the standard detail sheet, each barrier is 6096 mm in length. The concrete used to construct the barrier is designed to have a minimum 28-day compressive strength of 21 MPa with minimum and maximum entrained air contents of five and nine percent, respectfully. Reinforcement in each barrier segment consists of three vertical "V-shaped" stirrups on each end of the barrier fabricated from #13 bars. The first stirrup is located 140 mm from the end with the other two subsequently spaced 146 mm apart. The longitudinal reinforcement in the barriers consists of four #16 bars along the length of the barrier. The barriers used in the test installation were constructed using the "Alternate Joint Connection" as shown on the standard drawing sheet. The barriers were constructed by Concrete Safety Systems located in Bethel, Pennsylvania. A representative from NYDOT was present during construction to insure that the barriers and barrier connecting hardware were constructed in accordance with NYDOT specifications.

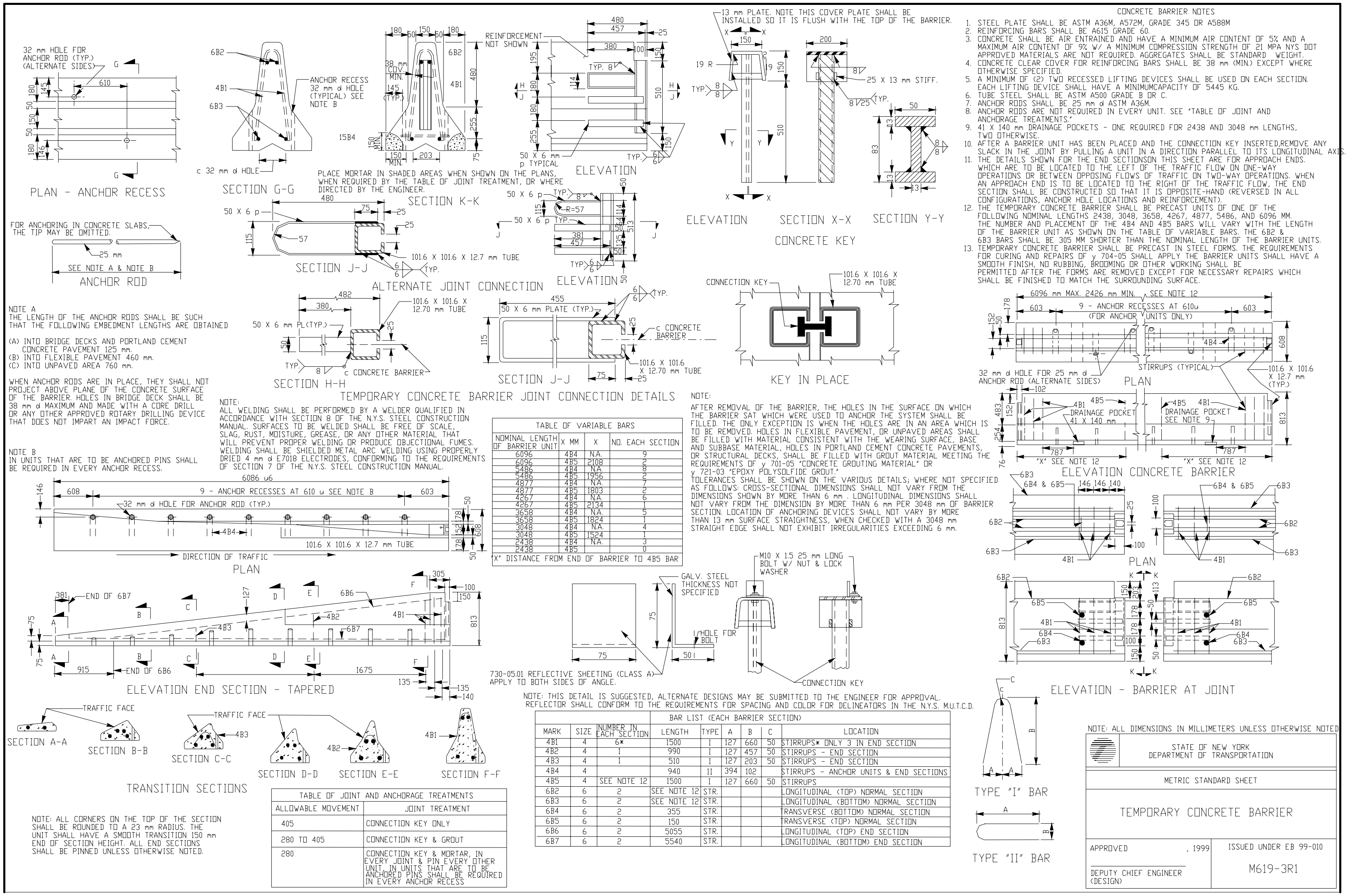


Figure 1. Details of the NYDOT PCB.

The barrier segments are connected to one another using a steel “I-shaped” connection key which fits inside steel tubes cast into each end of the barrier sections. The steel tubes are fabricated from ASTM A500 Grade B or C material and have dimensions of 102 mm x 102 mm x 13 mm thick. The tubes are 513 mm in length and have a 25-mm slot cut into the exposed face of the tube at the end of the barrier segment. The steel tubes are anchored inside the barrier using three 50-mm wide x 6-mm thick bent steel straps attached to the tubes as shown in the “Alternate Joint Connection” detail. The straps extend 380 mm beyond the tube into the barrier segment. The top strap is oriented with its sides in the horizontal plane with the ends of the strap welded to the back of the tube with 8-mm fillet welds. The bottom two straps are oriented with their sides in the vertical plane with the ends of the strap welded to the sides of the tube with 6-mm fillet welds.

The steel “I-shaped” connection keys are constructed from three 13-mm plates welded together with four 8-mm filet welds. Two plates make up the flanges of the “I-shape” with the third plate used as the web. The flanges of the key are 50-mm wide. The total depth of the connection key is 83 mm. The steel used for the “I-shaped” connection keys is ASTM A36M, A572M, Grade 345 or A588M material.

The test installation consisted of ten barrier sections connected together using the steel connection keys for a total test installation length of approximately 61.0 m. The barrier sections were placed on an existing concrete runway located at the TTI test facility. At the request of the Federal Highway Administration, all longitudinal slack was removed from the joints as the barrier segments were placed. The layout of the test installation is shown in figure 2. Photographs of the completed test installation are shown in figures 3 and 4.

Test Conditions

According to *NCHRP Report 350*, two tests are required to evaluate longitudinal barriers, such as the New York DOT portable concrete barriers, to test level three (TL-3). Conditions of these tests are as described below:

> ***NCHRP Report 350* test designation 3-10**: This test involves an 820-kg passenger car impacting the critical impact point (CIP) of the length of need (LON) of the longitudinal barrier at a nominal speed and angle of 100 km/h and 20 degrees, respectively. The purpose of this test is to evaluate the overall performance of the LON section in general and, occupant risk in particular.
>
> ***NCHRP Report 350* test designation 3-11**: This test involves a 2000-kg pickup truck impacting the CIP of the LON at a nominal speed and angle of 100 km/h and 25 degrees, respectively. The purpose of this test is to evaluate the strength of the barrier and its ability to contain and redirect the pickup truck in a stable manner.

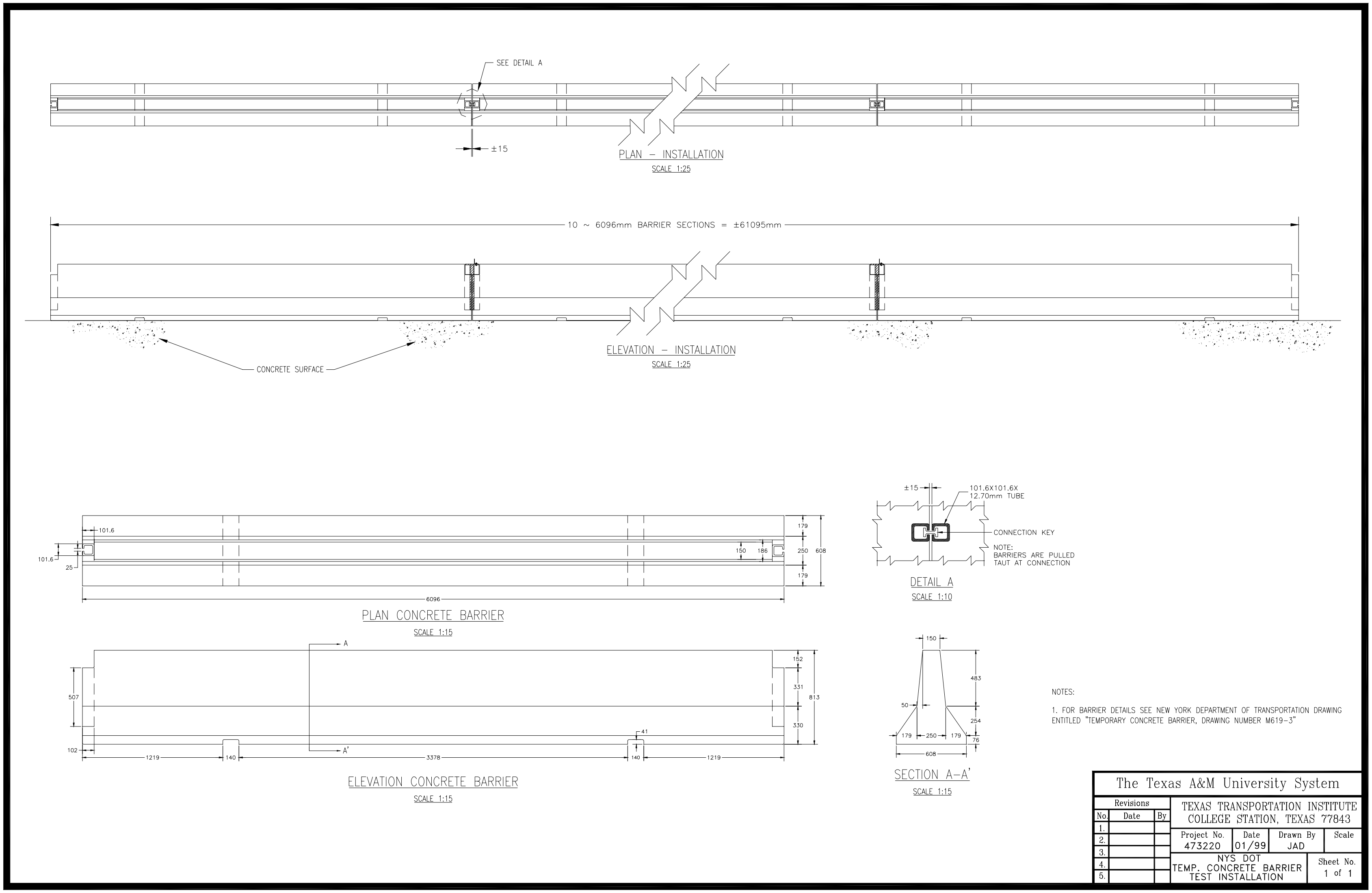


Figure 2. Layout and connection of NYDOT PCB installation prior to testing.

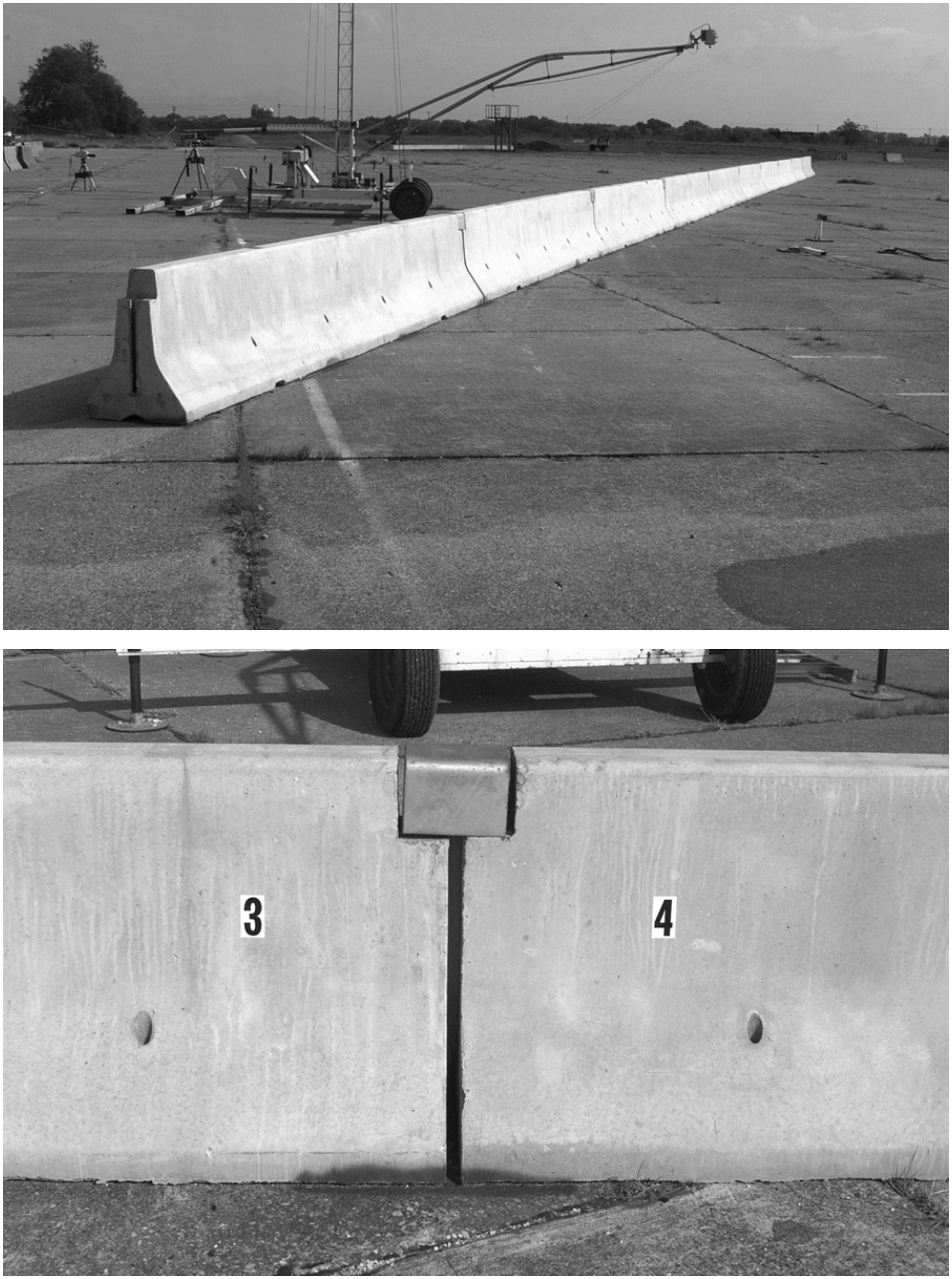


Figure 3. NYDOT PCB prior to testing.

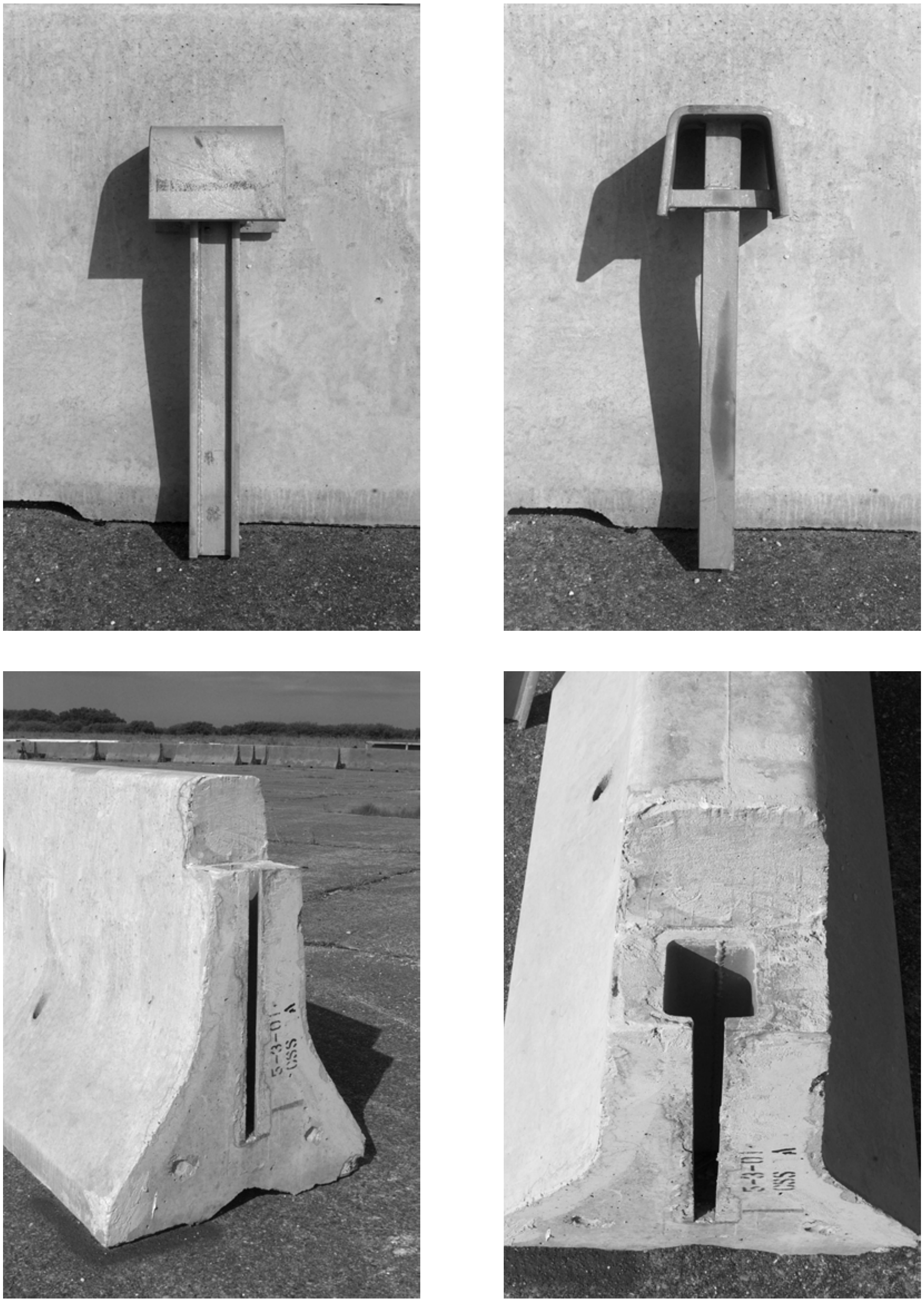


Figure 4. I-beam connection prior to testing.

NCHRP Report 350 test designation 3-11 was performed on the New York DOT PCB with I-beam connection (test no. 473220-14) and the details and results are reported herein. The CIP for this test was determined using information contained in *NCHRP Report 350*. The CIP was determined to be 1.3 m upstream of the joint nearest the one-third point of the LON.

All crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented in appendix A.

Evaluation Criteria

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

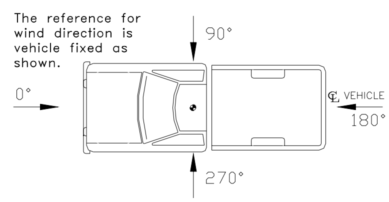
CRASH TEST 473220-14 (*NCHRP REPORT 350* TEST NO. 3-11)

Test Vehicle

A 1996 Chevrolet 2500 pickup truck, shown in figures 5 and 6, was used for the crash test. Test inertia weight of the vehicle was 2000 kg, and its gross static weight was 2076 kg. The height to the lower edge of the vehicle front bumper was 365 mm, and the height to the upper edge of the front bumper was 595 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 12. 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 crash test was performed the morning of June 22, 2001. The day before the test 59 mm of rainfall was recorded, and seven days before the test 29 mm of rainfall was recorded. No other rainfall was recorded for a period of ten days prior to the test. Weather conditions at the time of testing were as follows: Wind Speed: 10 km/h; Wind Direction: 0 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); Temperature: 28°C; Relative Humidity: 72 percent.



Impact Description

The 2000-kg pickup truck, traveling at 100.8 km/h, impacted the NYDOT PCB 1.38 m upstream of the joint between segments 3 and 4, at an impact angle of 25.6 degrees. Shortly after impact, segment 3 began to deflect, and at 0.017 s the left front wheel began to ride up the face of the PCB. The left front tire deflated at 0.067 s and the vehicle began to redirect at 0.196 s. At 0.196 s, the vehicle was traveling parallel with the barrier at a speed of 80.5 km/h. The vehicle was totally airborne at 0.286 s. At 0.409 s the vehicle lost contact with the barrier while traveling at a speed of 81.8 km/h and an exit angle of 11.3 degrees. The front wheels of the vehicle returned to the ground surface at 0.545 s, and by 0.937 s the rear wheels had recontacted the ground. Brakes on the vehicle were applied at 1.9 s. The vehicle yawed counterclockwise and came to rest in an upright position 54.1 m downstream from impact and 7.6 m forward of the traffic side of the original face of the barrier with the nose of the vehicle facing the barrier. Sequential photographs of the test period are shown in appendix C, figures 13 and 14.

Figure 5. Vehicle/installation geometrics for test 473220-14.

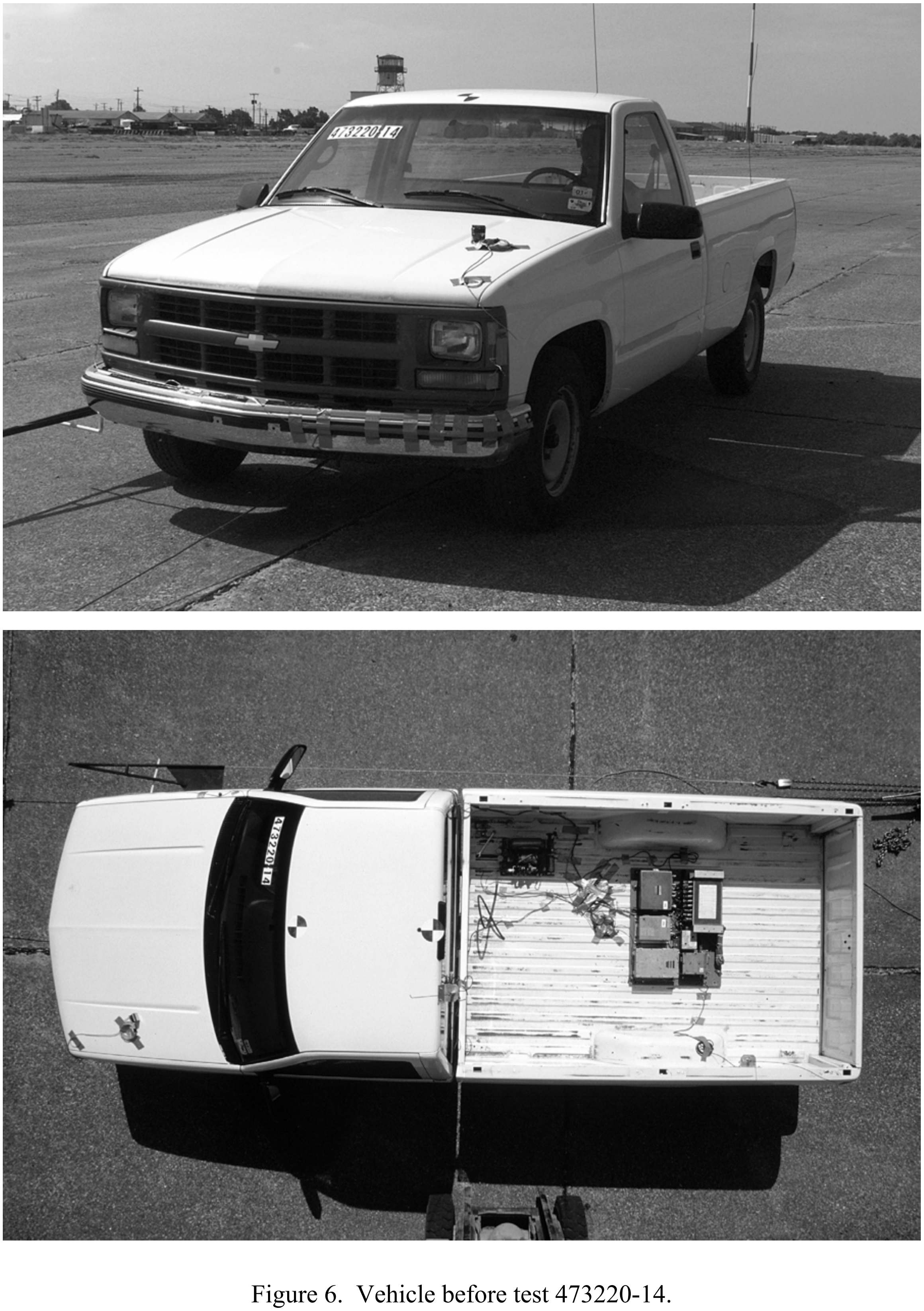


Figure 6. Vehicle before test 473220-14.

Damage to Test Article

As shown in figures 7 and 8, the NYDOT PCB sustained moderate damage. The upstream end was displaced 148 mm downstream, and the downstream end was pulled 5 mm upstream. Tire marks were observed along the end of segment 3, across the face of segment 4, and the top of segment 5. Some spawling and cracking of concrete occurred in segments 3, 4, and 5. Total length of contact of the vehicle with the barrier was 9.2 m. Maximum lateral permanent deflection was 1.27 m at the joint between segments 3 and 4. Maximum lateral dynamic deflection was also 1.27 m.

Vehicle Damage

The following vehicle components were structurally damaged: stabilizer bar, rod ends, left upper and lower A-arms, left front frame rail, and left side firewall and floor pan. Also damaged were the front bumper, fan, radiator, left front quarter panel, left front tire and wheel rim, left door, left side of bed, and the left rear tire and wheel rim. Exterior crush to the vehicle was 420 mm in the frontal plane and 330 mm in the left side plane, both at the left front corner at bumper height. Damage to the vehicle is shown in figure 9. Maximum occupant compartment deformation was 60 mm in the center floor pan area. Photographs of the interior of the vehicle are shown in figure 10. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 2 and 3.

Occupant Risk Factors

Data from the triaxial accelerometer located at the vehicle c.g. were digitized to compute occupant impact velocity and ridedown accelerations. In the longitudinal direction, occupant impact velocity was 3.9 m/s at 0.109 s, maximum 0.010-s ridedown acceleration was -6.2 g's from 0.639 to 0.649 s, and the maximum 0.050-s average was -5.9 g's between 0.015 and 0.065 s. In the lateral direction, the occupant impact velocity was 5.6 m/s at 0.109 s, the highest 0.010-s occupant ridedown acceleration was 8.9 g's from 0.222 to 0.232 s, and the maximum 0.050-s average was 10.0 g's between 0.018 and 0.068 s. Only the occupant impact velocity and ridedown acceleration in the longitudinal axis of the vehicle are required for evaluation of Criterion L of *NCHRP Report 350*. These data and other information pertinent to the test are presented in figure 11. Vehicle angular displacements and accelerations versus time traces are shown in appendix E, figures 15 through 21.

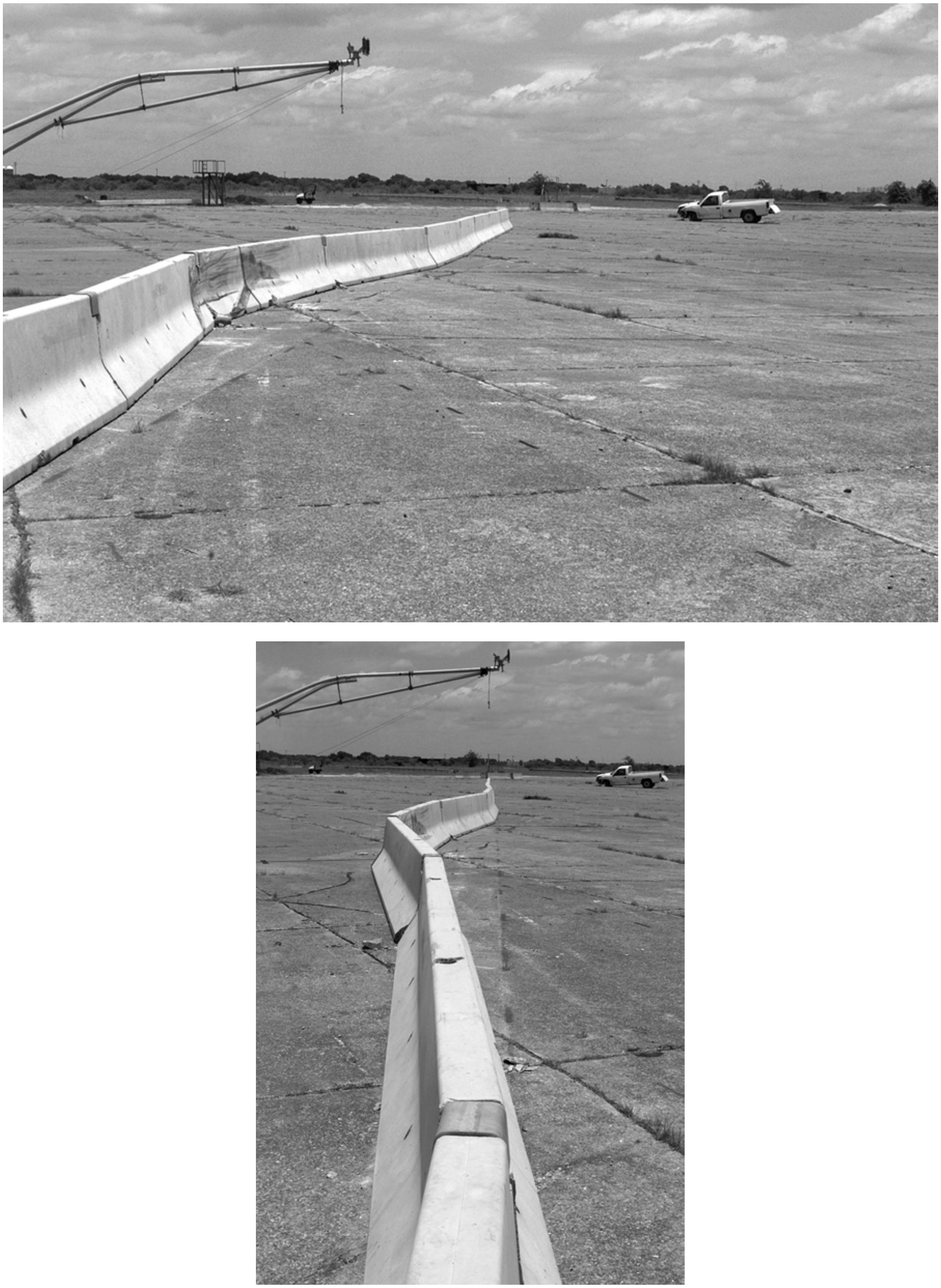


Figure 7. Vehicle trajectory after test 473220-14.

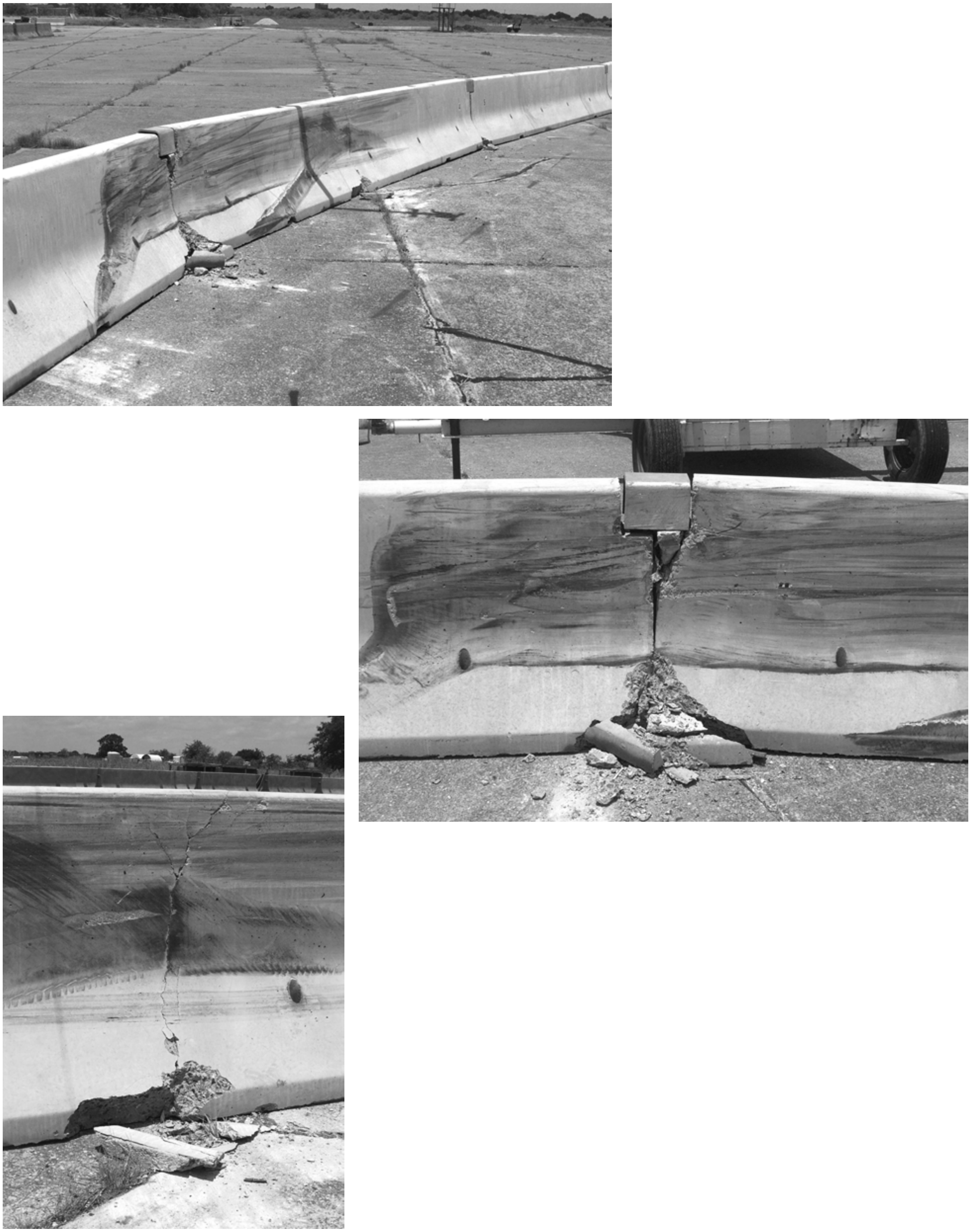


Figure 8. Installation after test 473220-14.

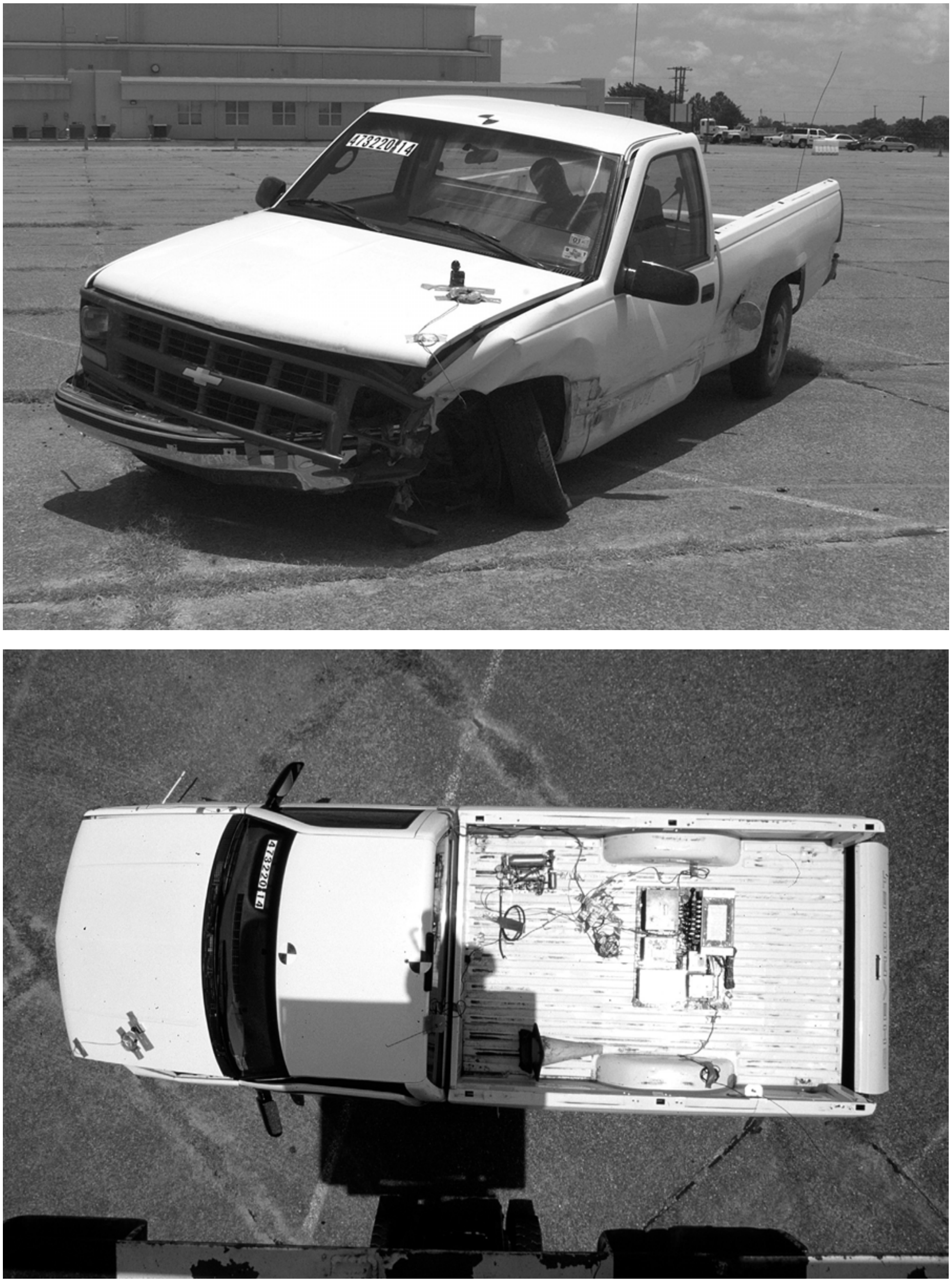
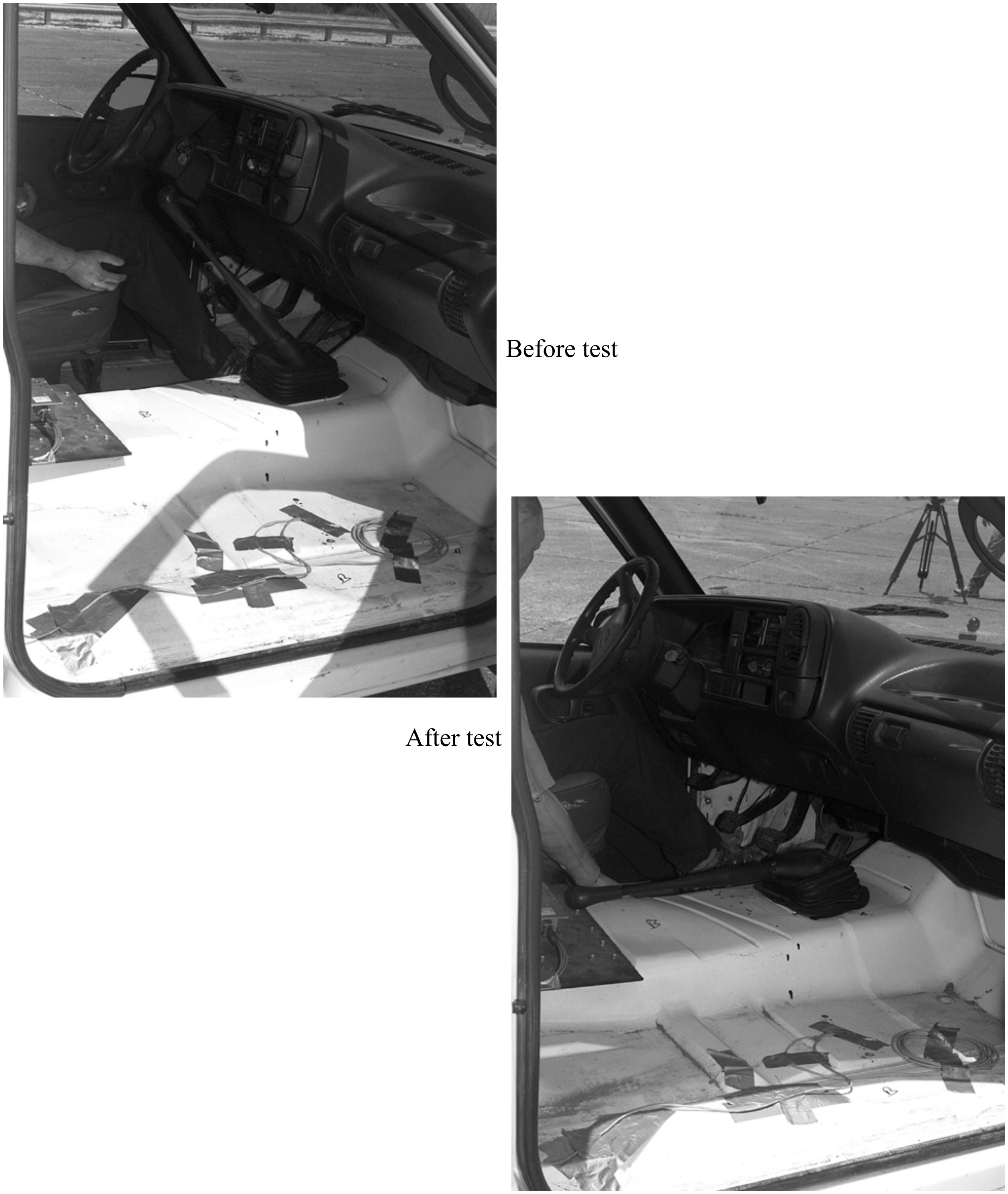


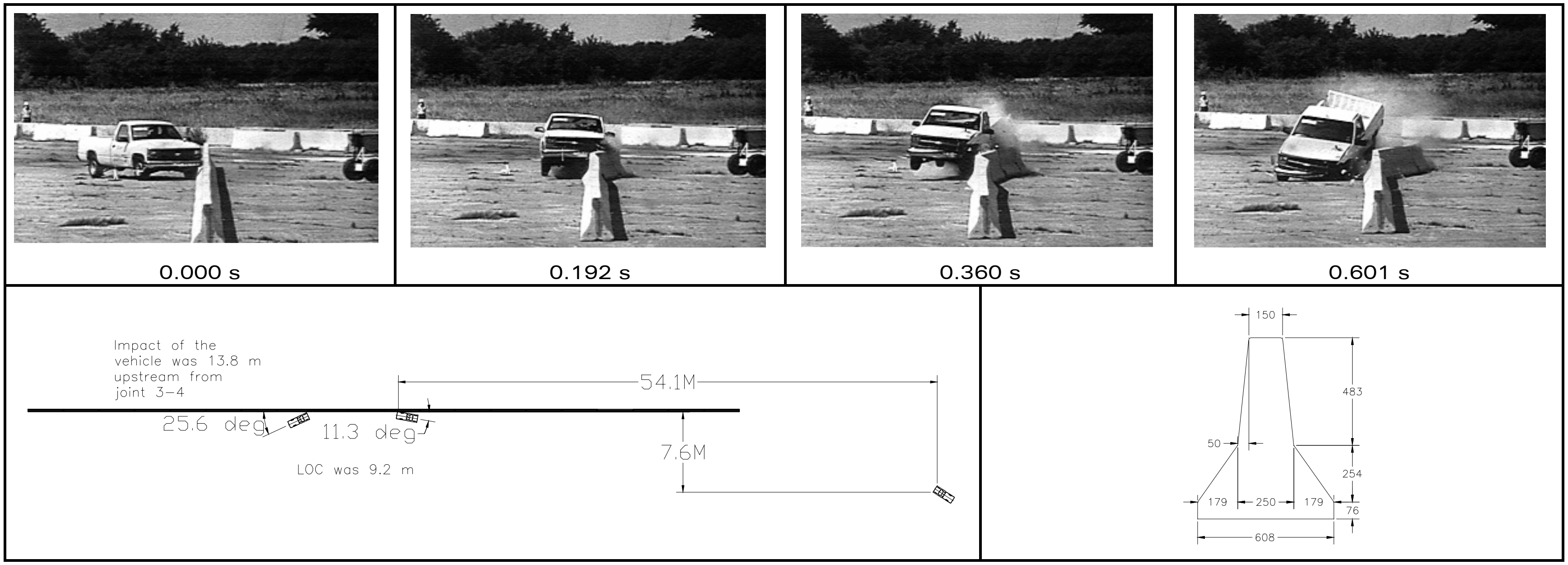
Figure 9. Vehicle after test 473220-14.



Before test

After test

Figure 10. Interior of vehicle for test 473220-14.



General Information	
Test Agency	Texas Transportation Institute
Test No.	473220-14
Date	06/28/01
Test Article	
Type	Median Barrier
Name	New York DOT PCB
Installation Length (m)	61.0
Material or Key Elements	10 @ 6.1-m Long Reinforced Jersey Shape PCB with I-Beam Connection
Soil Type and Condition	Concrete Pavement, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	1996 Chevrolet 2500 pickup truck
Mass (kg)	
Curb	1897
Test Inertial	2000
Dummy	76
Gross Static	2076

Impact Conditions	
Speed (km/h)	100.8
Angle (deg)	25.6
Exit Conditions	
Speed (km/h)	81.8
Angle (deg)	11.3
Occupant Risk Values	
Impact Velocity (m/s)	
x-direction	3.9
y-direction	-5.6
THIV (km/h)	23.5
Ridedown Accelerations (g's)	
x-direction	-6.2
y-direction	8.9
PHD (g's)	8.9
ASI	1.28
Max. 0.050-s Average (g's)	
x-direction	-5.9
y-direction	10.0
z-direction	-7.4

Test Article Deflections	
(m)	1.27
Dynamic	1.27
Permanent	1.71
Working Width	
Vehicle Damage	
Exterior	11LFQ2
VDS	11FLEK2
CDC	&11LYEW2
Maximum Exterior Vehicle Crush (mm)	420
Interior	LF0102000
OCDI	
Max. Occ. Compart. Deformation (mm)	60
Post-Impact Behavior	
(during 1.0 s after impact)	46
Max. Yaw Angle (deg)	51
Max. Pitch Angle (deg)	-19
Max. Roll Angle (deg)	

Figure 11. Summary of results for test 473220-14, *NCHRP Report 350* test 3-11.

SUMMARY AND CONCLUSIONS

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 NYDOT PCB contained and redirected the 2000-kg pickup truck in a controlled manner. The vehicle did not penetrate, underride or override the barrier. Maximum lateral dynamic deflection was 1.27 m. *(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 was present to penetrate, or to show potential for penetrating the occupant compartment, or to present a hazard to others in the area. Maximum occupant compartment deformation was only 60 mm in the center floor pan area. *(pass)*

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

Results: The 2000-kg pickup truck 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 7.6 m forward of the face of the barriers and would likely have intruded into adjacent traffic lanes. *(fail) note: compliance with Criterion is preferable but not required.*

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 3.9 m/s and ridedown acceleration was -6.2 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 11.3 degrees, which was 44 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:

◆ **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 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
<u>e. Major structural damage</u>

2. Windshield Damage

<u>a. None</u>
b. Minor chip or crack
c. Broken, no interference with visibility
d. Broken and 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
<u>d. Substantial, replacement parts needed for repair</u>
e. Cannot be repaired

CONCLUSIONS

During a previous test of the NYDOT PCB, the joint on both ends of the barrier segment immediately downstream of the point of impact failed, causing the segment to displace 5.2 m behind the installation and the pickup truck to overturn.[3] Upon inspection of the failed connectors, it was determined that they were not fabricated following NYDOT standards and specifications. The tested barrier had only 24 percent of its intended connection capacity due to improper weld length, size, and penetration.

Analysis indicated that a PCB properly fabricated according to NYDOT standards and specifications should have adequate strength to perform satisfactorily and meet the evaluation criteria set forth in *NCHRP Report 350*. Thus, a recommendation was made to fabricate new barrier segments with the proper welding details and re-run *NCHRP Report 350* test 3-11 with the new barrier segments.

For the test reported herein, the concrete barrier segments and steel I-beam connectors were fabricated and inspected by approved NYDOT contractors according to NYDOT standards and specifications. During this repeat of *NCHRP Report 350* test 3-11, the I-beam connectors maintained their integrity and the barrier successfully contained and redirected the 2000-kg pickup truck. As summarized in table 1, the NYDOT PCB meets all required criteria for *NCHRP Report 350* test 3-11 and is considered suitable for implementation on the National Highway System (NHS).

Table 1. Performance evaluation summary for test 473220-14, *NCHRP Report 350* test 3-11.

Test Agency: Texas Transportation Institute	Test No.: 473220-14	Test Date: 06/22/2001
***NCHRP Report 350* 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 NYDOT PCB contained and redirected the 2000-kg pickup truck in a controlled manner. The vehicle did not penetrate, underride or override the barrier. Maximum lateral dynamic deflection was 1.27 m.	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 a hazard to others in the area. Maximum occupant compartment deformation was 60 mm in the center floor pan 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 may have intruded into adjacent traffic lanes as it came to rest 7.6 m forward of the face of the barriers.	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 3.9 m/s and ridedown acceleration was -6.2 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 11.3 degrees, which was 44 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

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 back-up 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 ±100 g 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 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. Pressure-sensitive switches on the bumper of the impacting vehicle are actuated 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 SAE J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to SAE J211 Mar95 *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 factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data are 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-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 system being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

An Alderson Research Laboratories Hybrid II, 50th percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 2000P vehicle. The dummy was uninstrumented.

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 is positioned on the impacting vehicle to indicate the instant of contact with the installation and is 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 event time, displacement, and angular data. A BetaCam, a VHS-format video camera, and still cameras were used to 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 is 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 is 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 so the tow vehicle moves away from the test site. A two-to-one speed ratio between the test and tow vehicle exists with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remains free-wheeling, i.e., no steering or braking inputs, until the vehicle clears the immediate area of the test site, at which time brakes on the vehicle are activated bringing it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

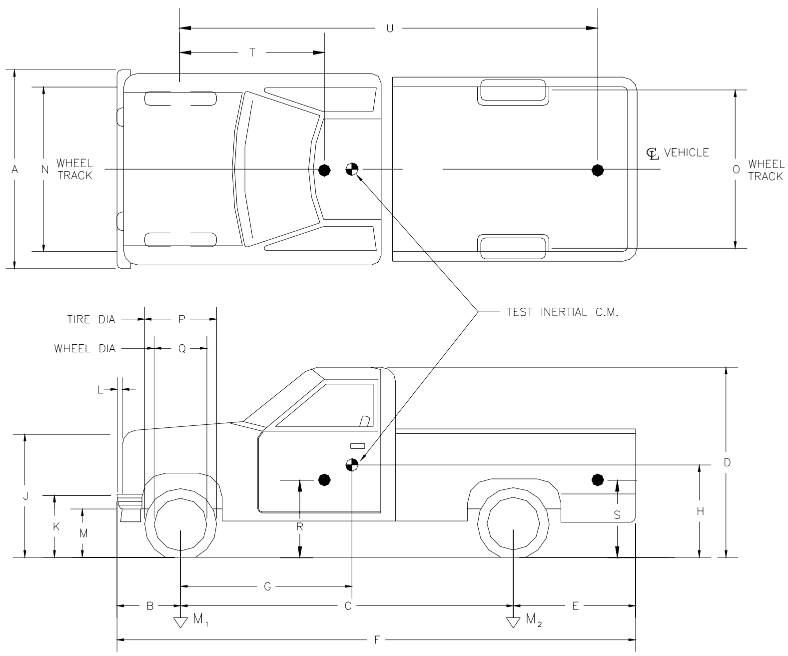
DATE: 06-22-01 TEST NO.: 473220-14 VIN NO.: 1GCFC24M1TZ135420

YEAR: 1996 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 172151 TIRE SIZE: LT 225 75R16

MASS DISTRIBUTION (kg) LF 590 RF 529 LR 448 RR 433

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

6 LUGS

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: Driver

GEOMETRY – (mm)

A	1870	E	1305	J	1030	N	1600	R	640
B	775	F	542	K	595	O	1615	S	850
C	3350	G	1475.7	L	75	P	730	T	1460
D	1760	H		M	365	Q	445	U	3500

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1122	1119	1163
M_2	775	881	913
M_T	1897	2000	2076

Figure 12. Vehicle properties for test 473220-14.

Table 2. Exterior crush measurements for test 473220-14.

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: Measure C1 to C6 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 Width ** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	Front bumper	800	420	740	420	310	175	75	50	30	-370
2	720 mm above ground	920	330	100	0	70	N/A	N/A	N/A	330	+1460
							Wheel Well				

[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.

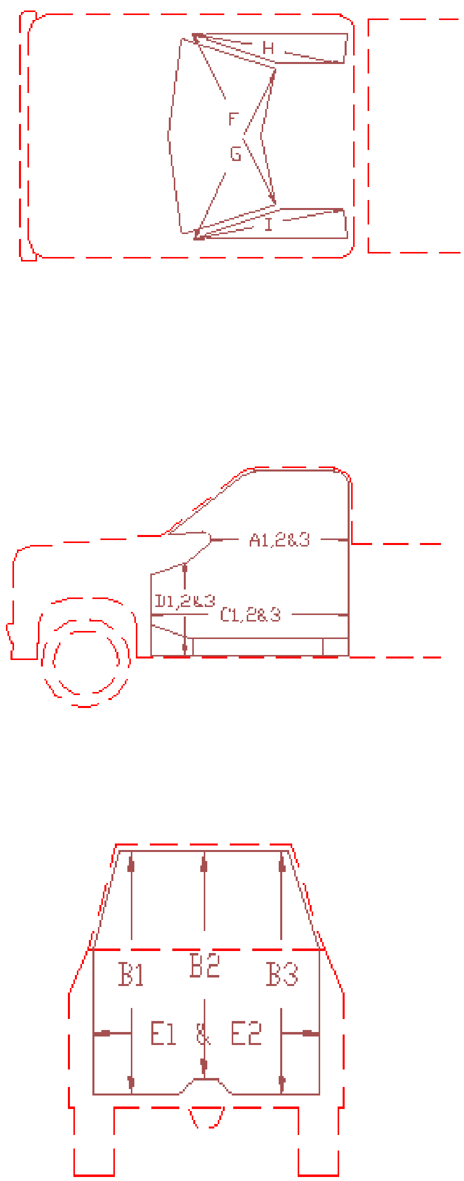
**Measure and document on the vehicle diagram the beginning or end of the direct damage width and field L (e.g., side damage with respect to undamaged axle).

***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 3. Occupant compartment measurements for test 473220-14.

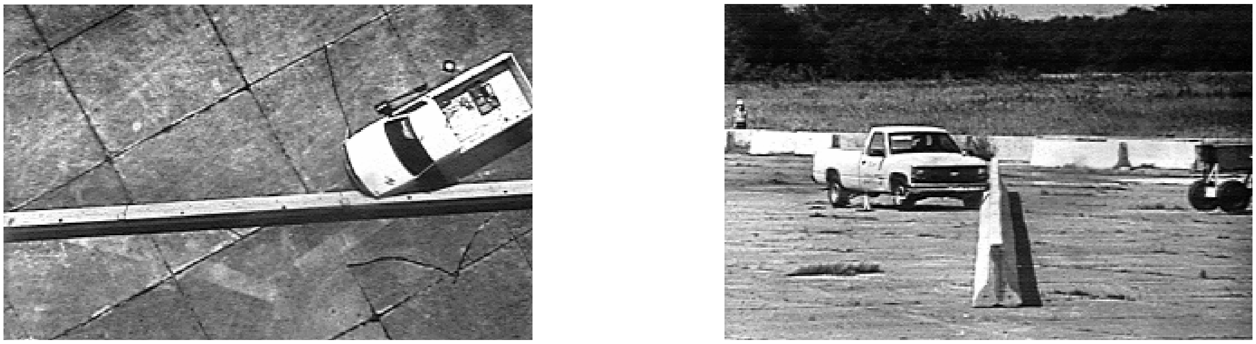
Truck

Occupant Compartment Deformation

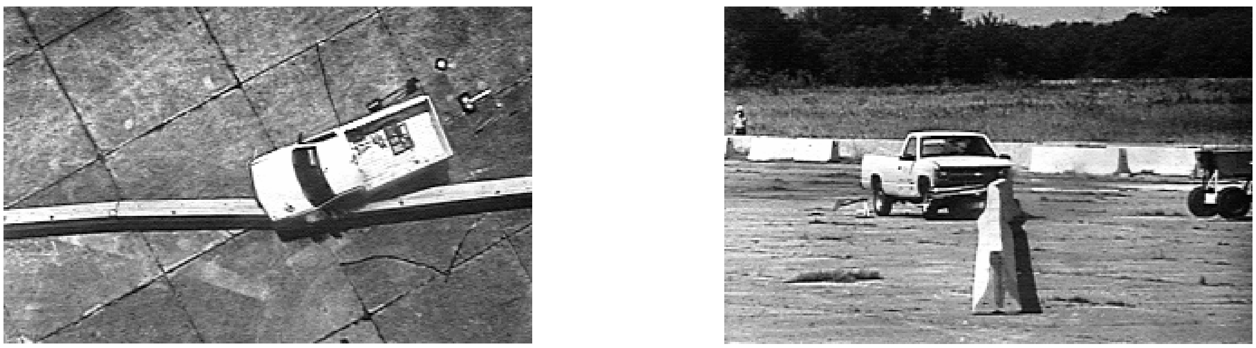


	BEFORE	AFTER
A1	866	842
A2	873	862
A3	907	907
B1	1082	1082
B2	1095	1035
B3	1066	1066
C1	1370	1338
C2	1248	1242
C3	1372	1372
D1	320	318
D2	162	140
D3	307	307
E1	1586	1603
E2	1592	1602
F	1460	1460
G	1460	1460
H	1000	1000
I	1000	1000
J	1522	1512

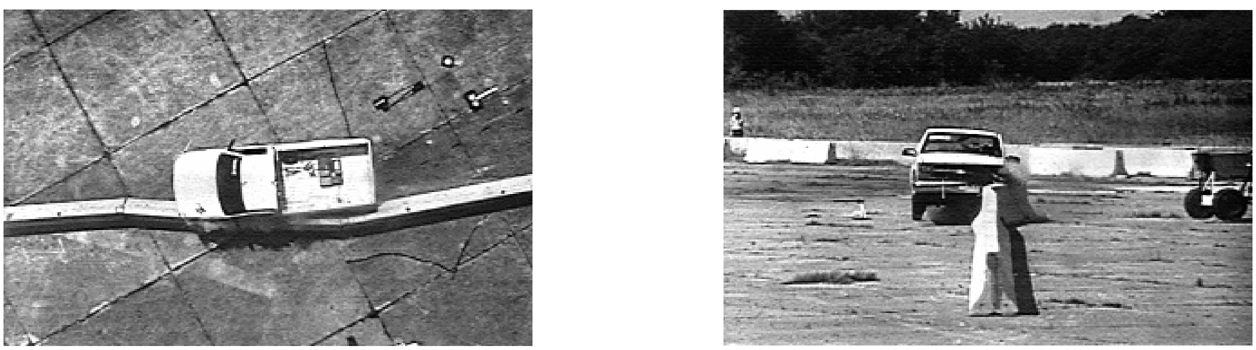
APPENDIX C. SEQUENTIAL PHOTOGRAPHS



0.000 s



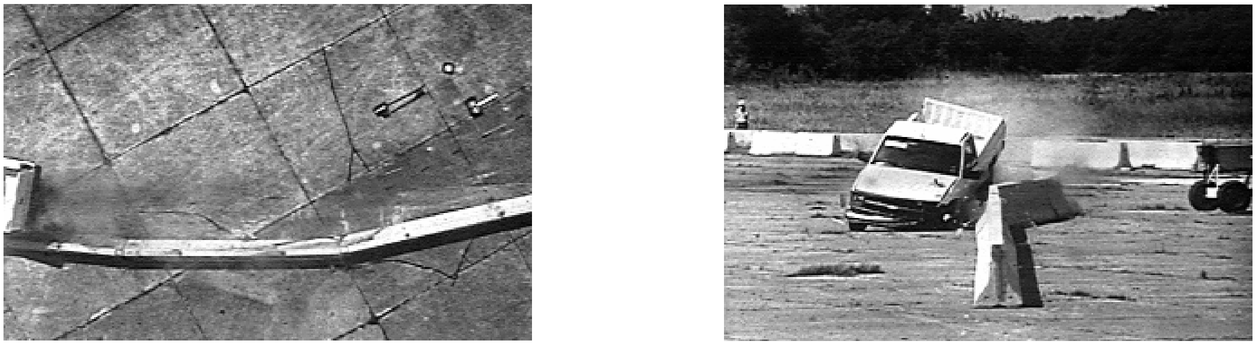
0.096 s



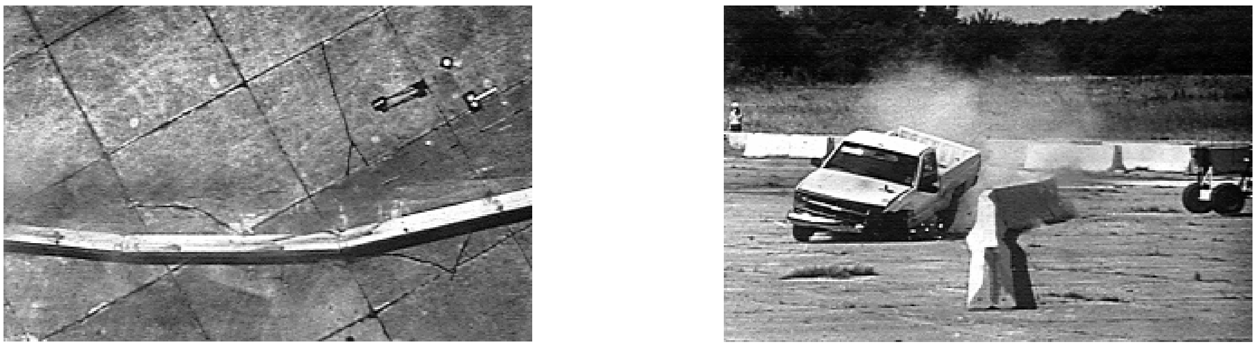
0.192 s

0.360 s

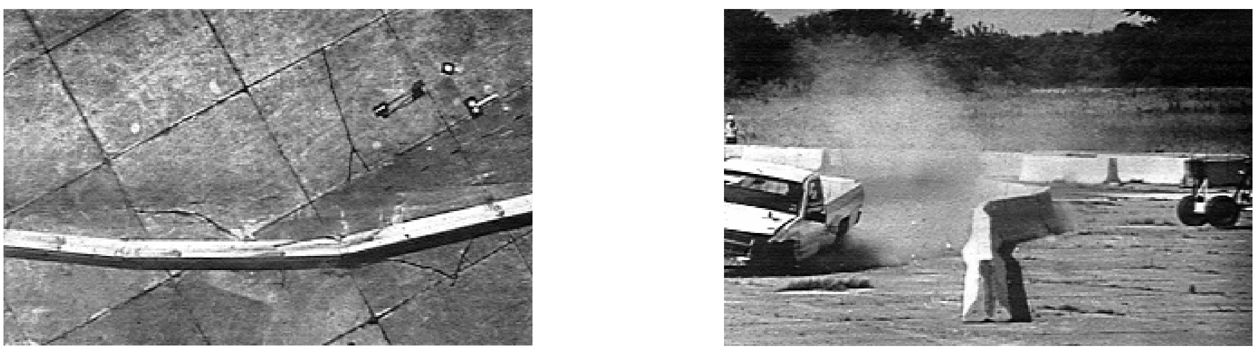
Figure 13. Sequential photographs for test 473220-14
(overhead & frontal views).



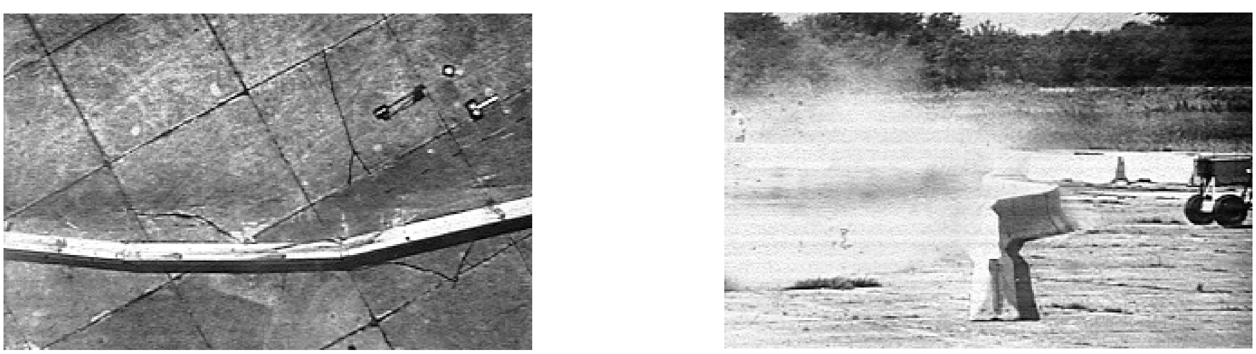
0.601 s



0.841 s



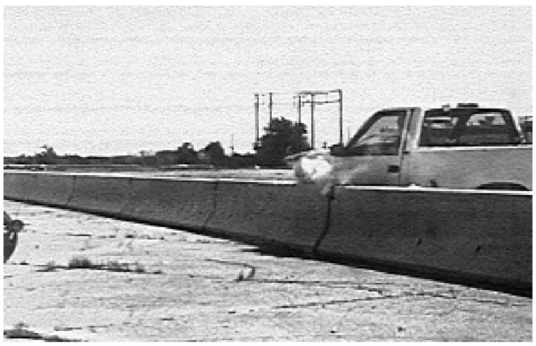
1.321 s



1.922 s

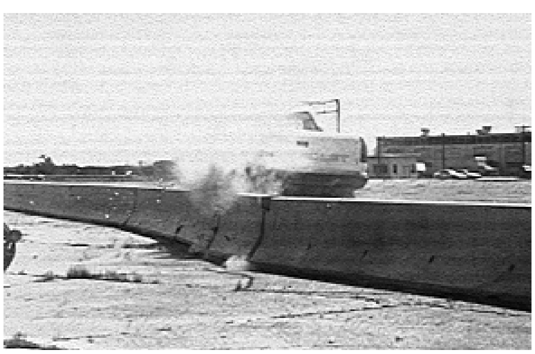
Figure 13. Sequential photographs for test 473220-14
(overhead & frontal views) (continued).

0.000 s

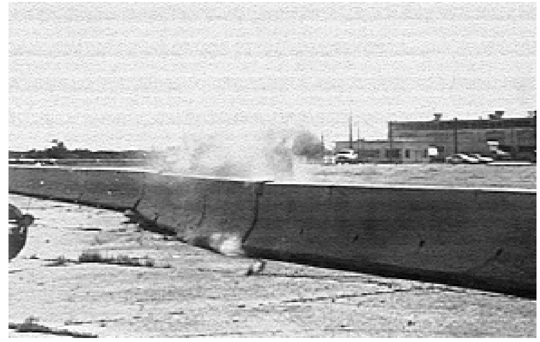


0.096 s

0.192 s

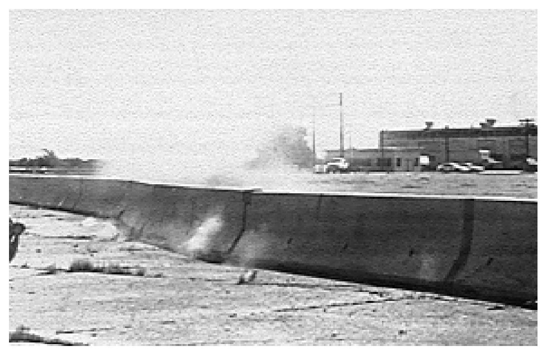


0.360 s

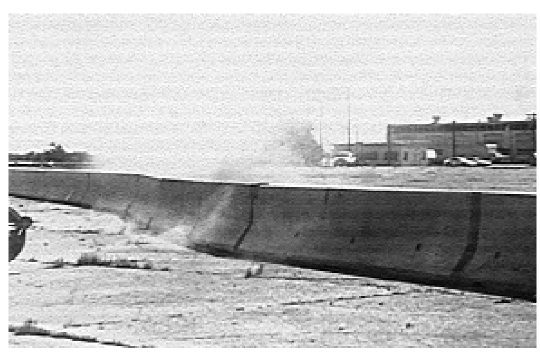


0.601 s

0.841 s

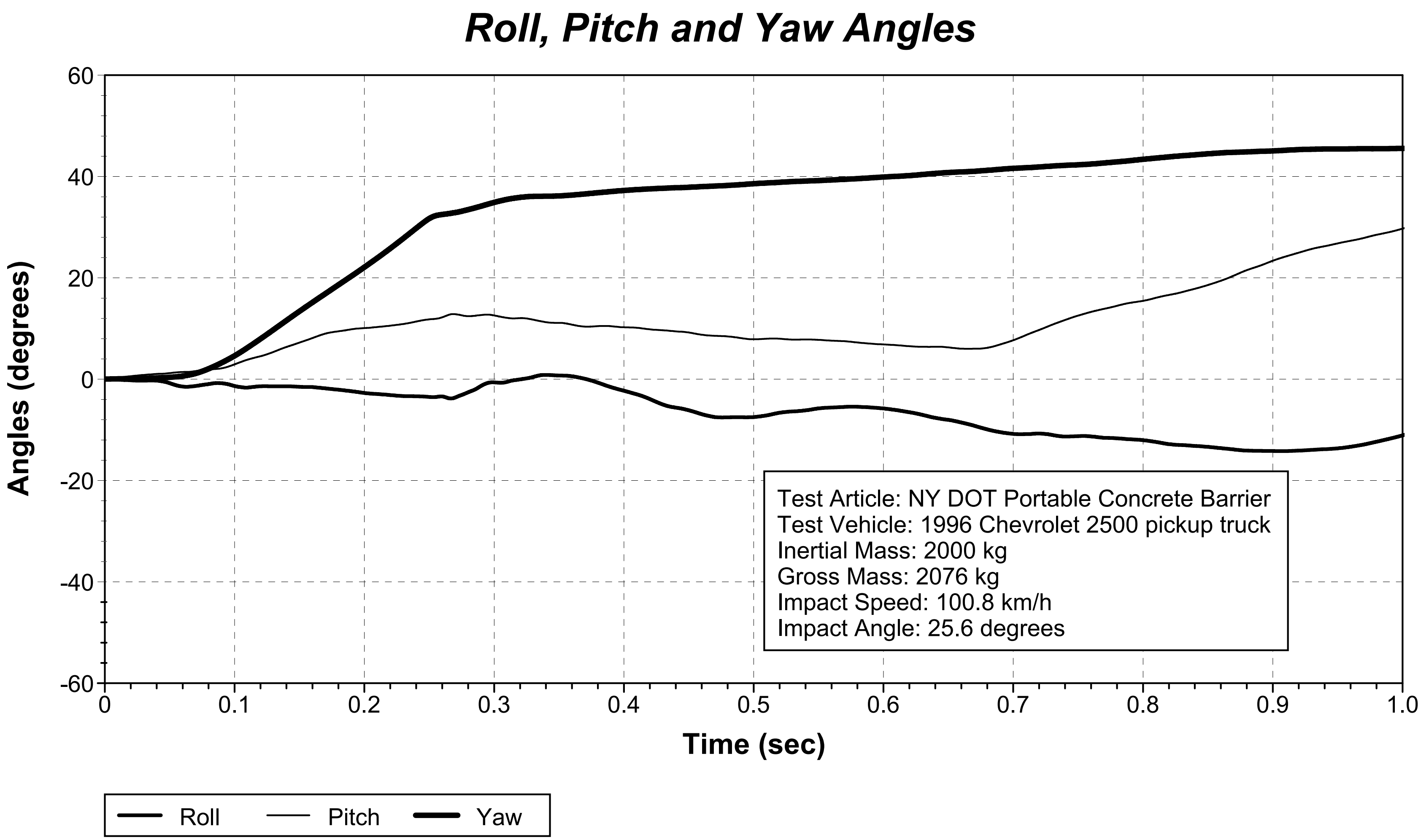


1.321 s



1.922 s

Figure 14. Sequential photographs for test 473220-14 (rear view).



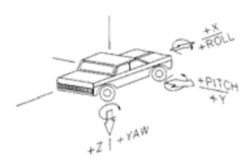


Figure 15. Vehicular angular displacements for test 473220-14.

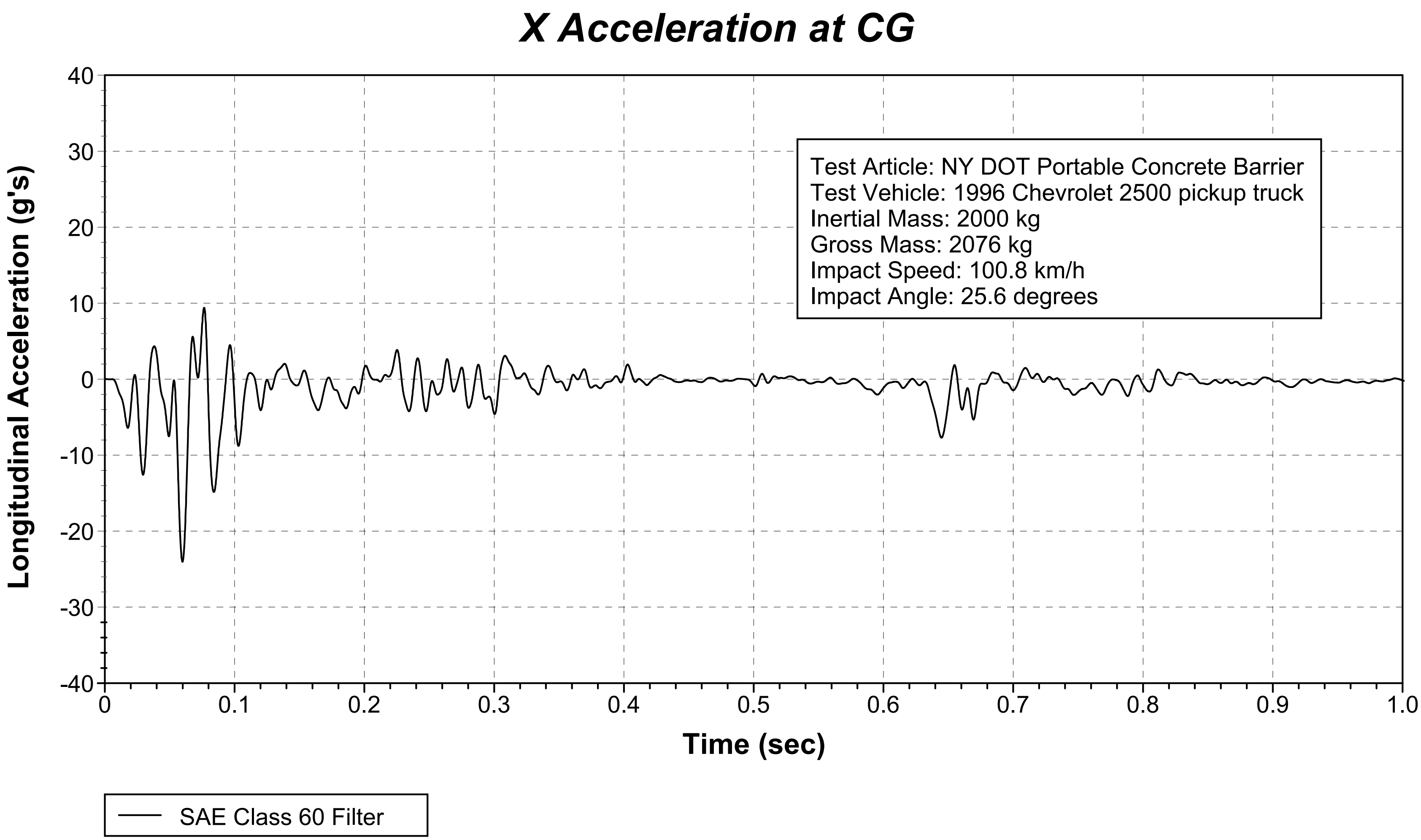


Figure 16. Vehicle longitudinal accelerometer trace for test 473220-14
(accelerometer located at center of gravity).

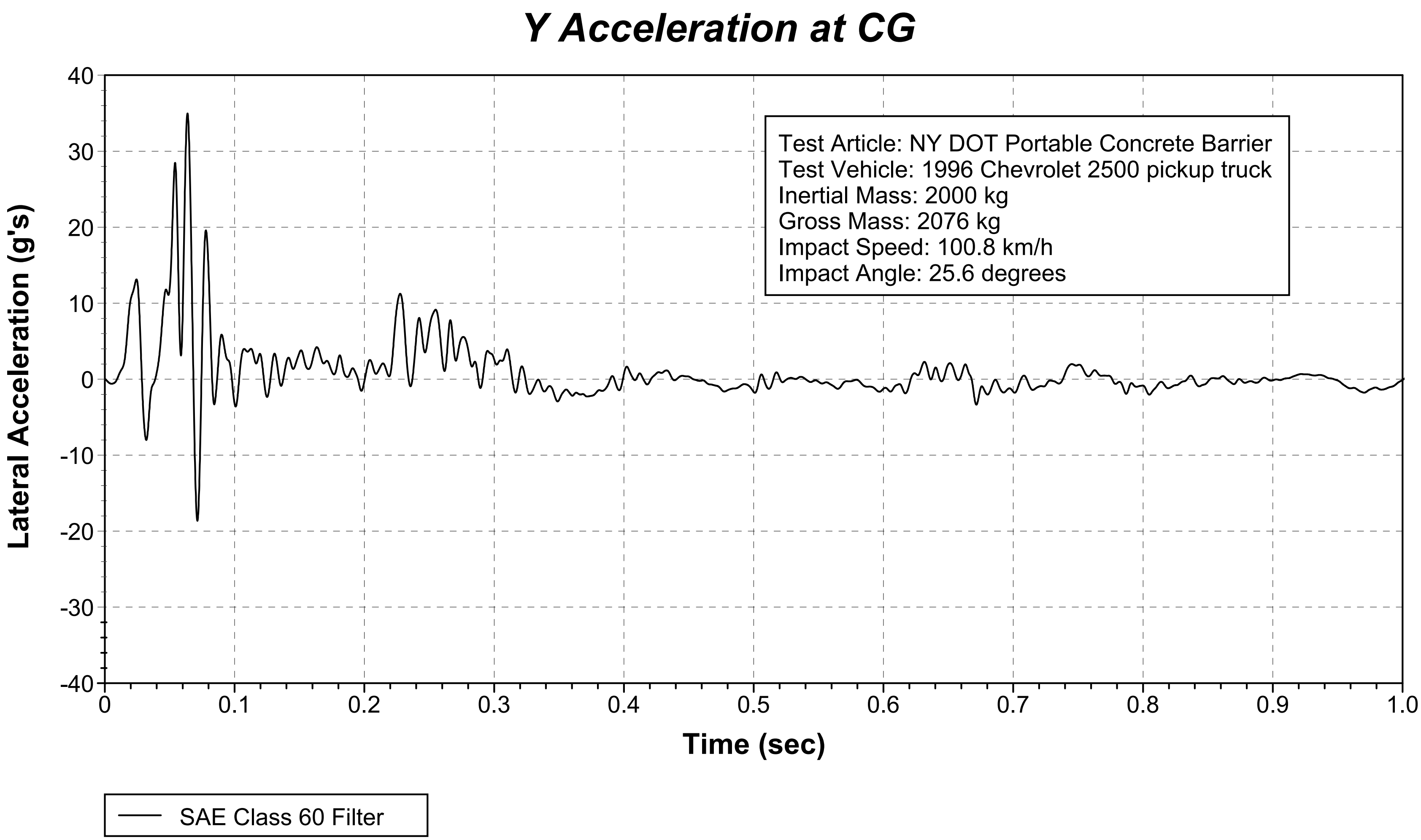


Figure 17. Vehicle lateral accelerometer trace for test 473220-14
(accelerometer located at center of gravity).

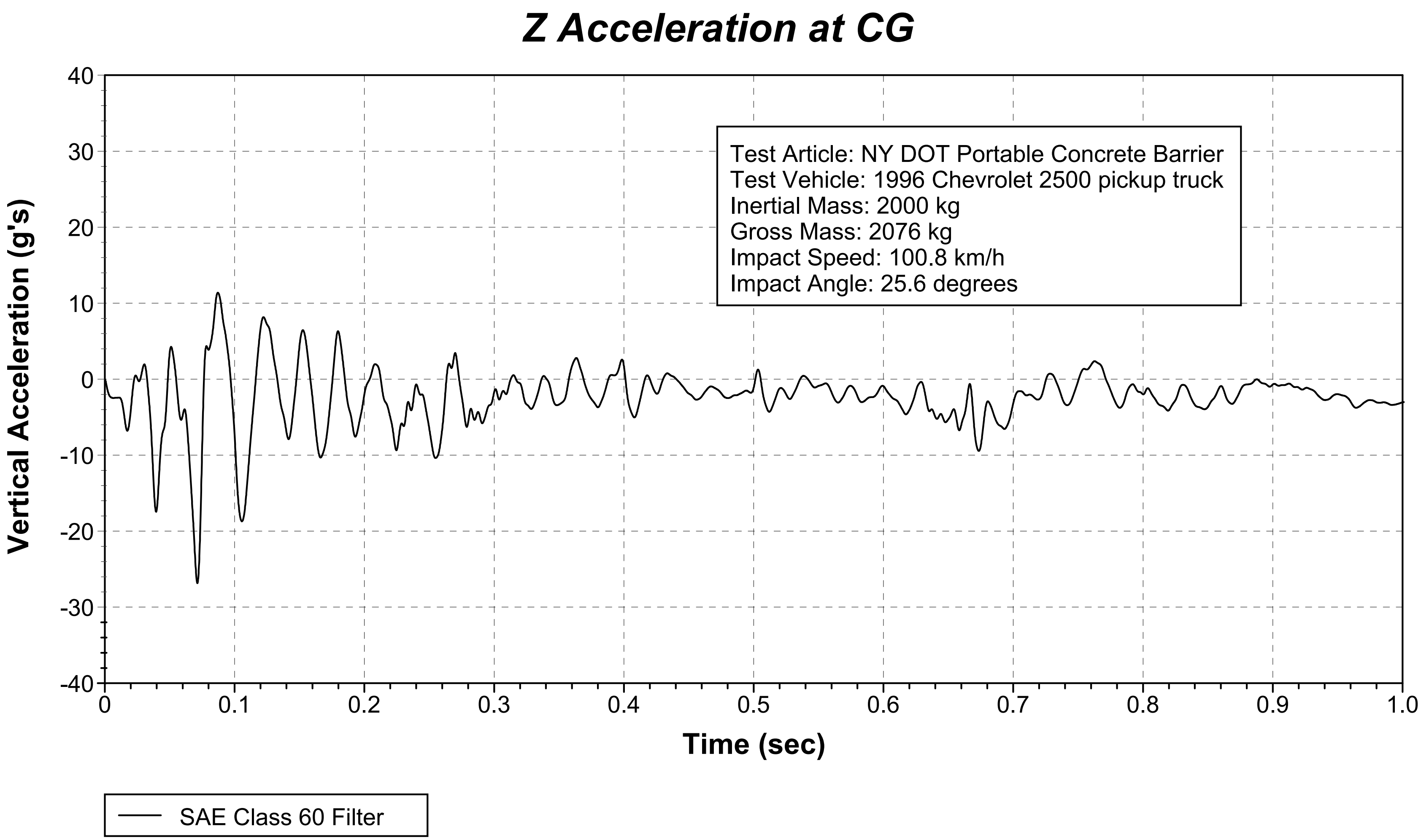


Figure 18. Vehicle vertical accelerometer trace for test 473220-14
(accelerometer located at center of gravity).

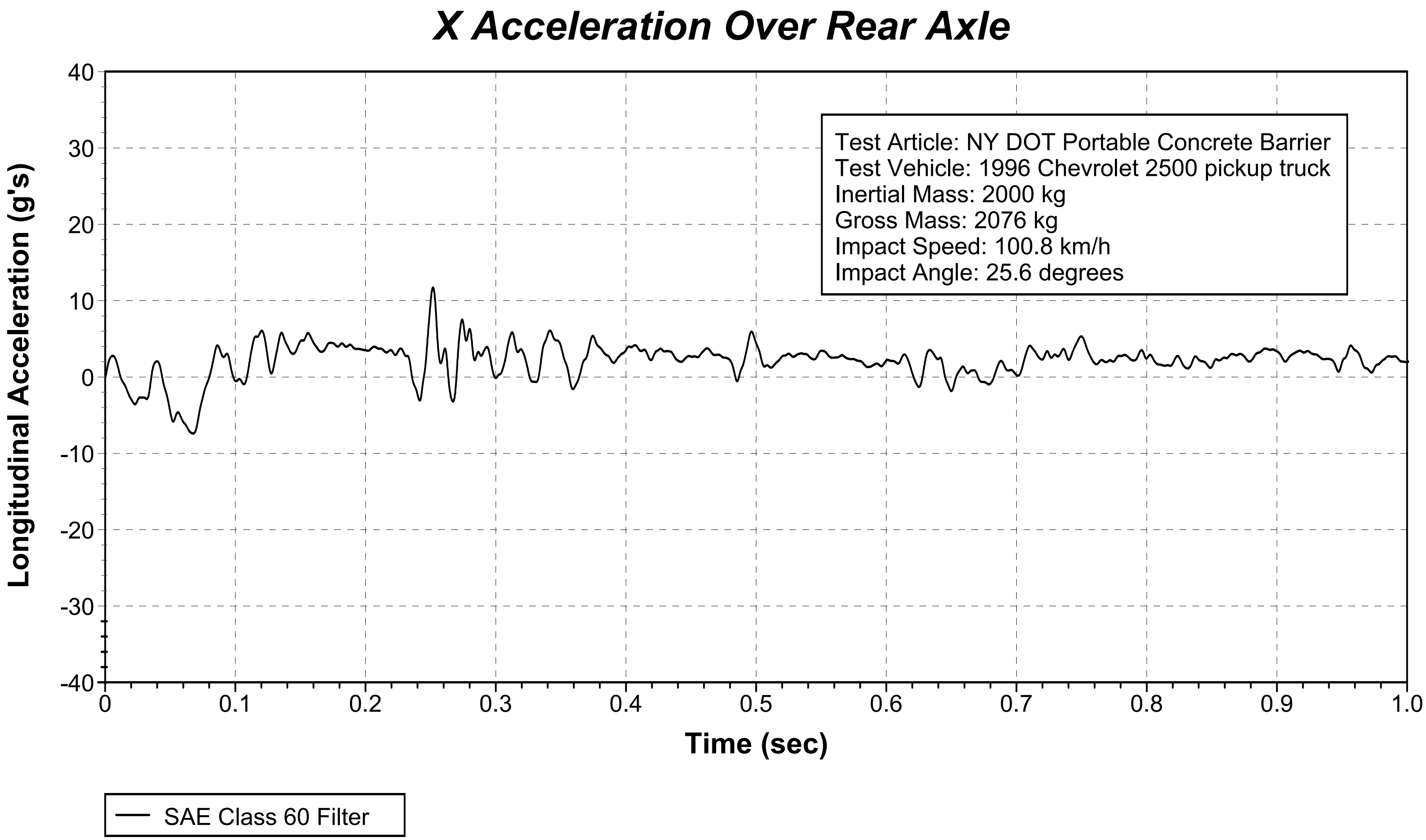


Figure 19. Vehicle longitudinal accelerometer trace for test 473220-14
(accelerometer located over rear axle).

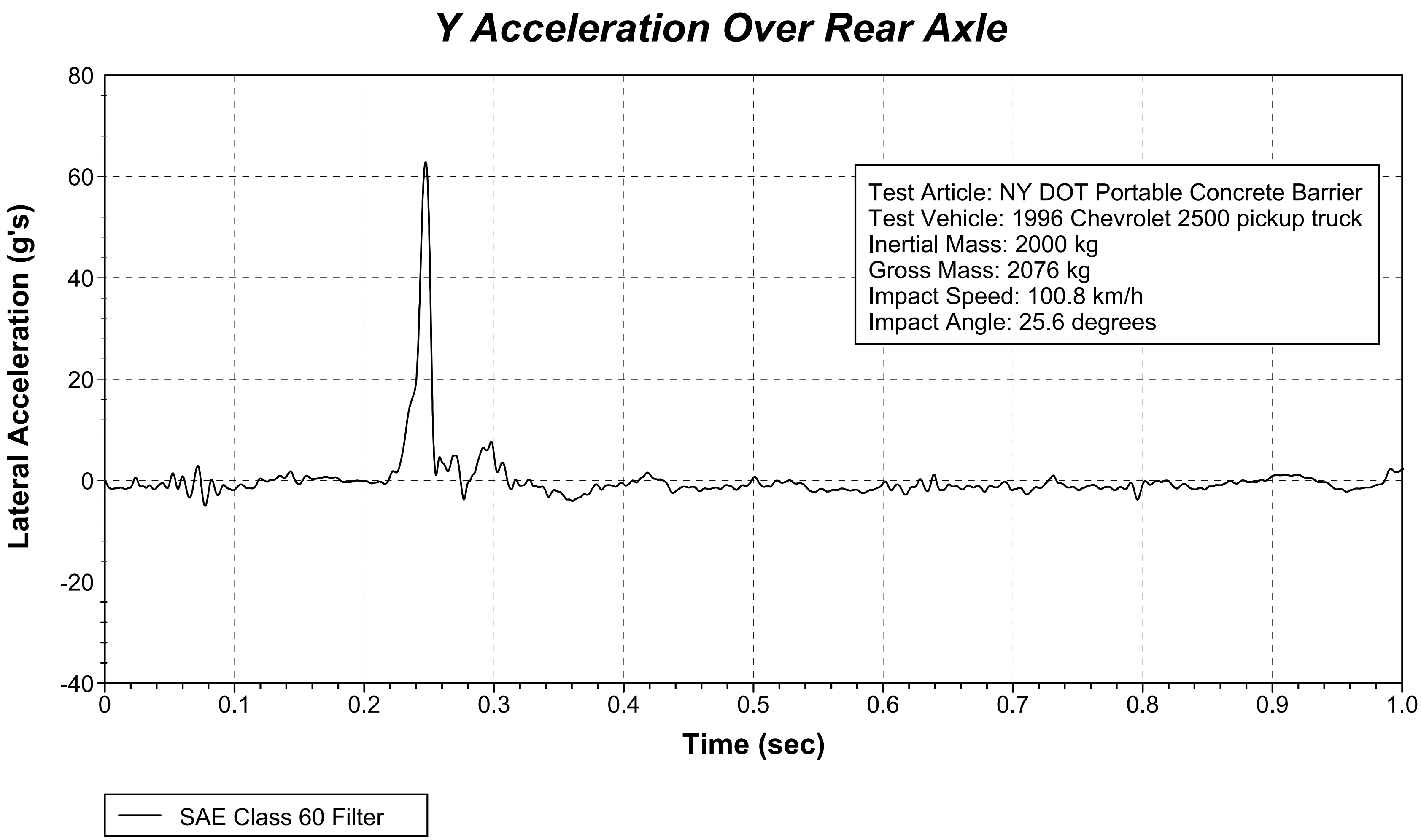


Figure 20. Vehicle lateral accelerometer trace for test 473220-14
(accelerometer located over rear axle).

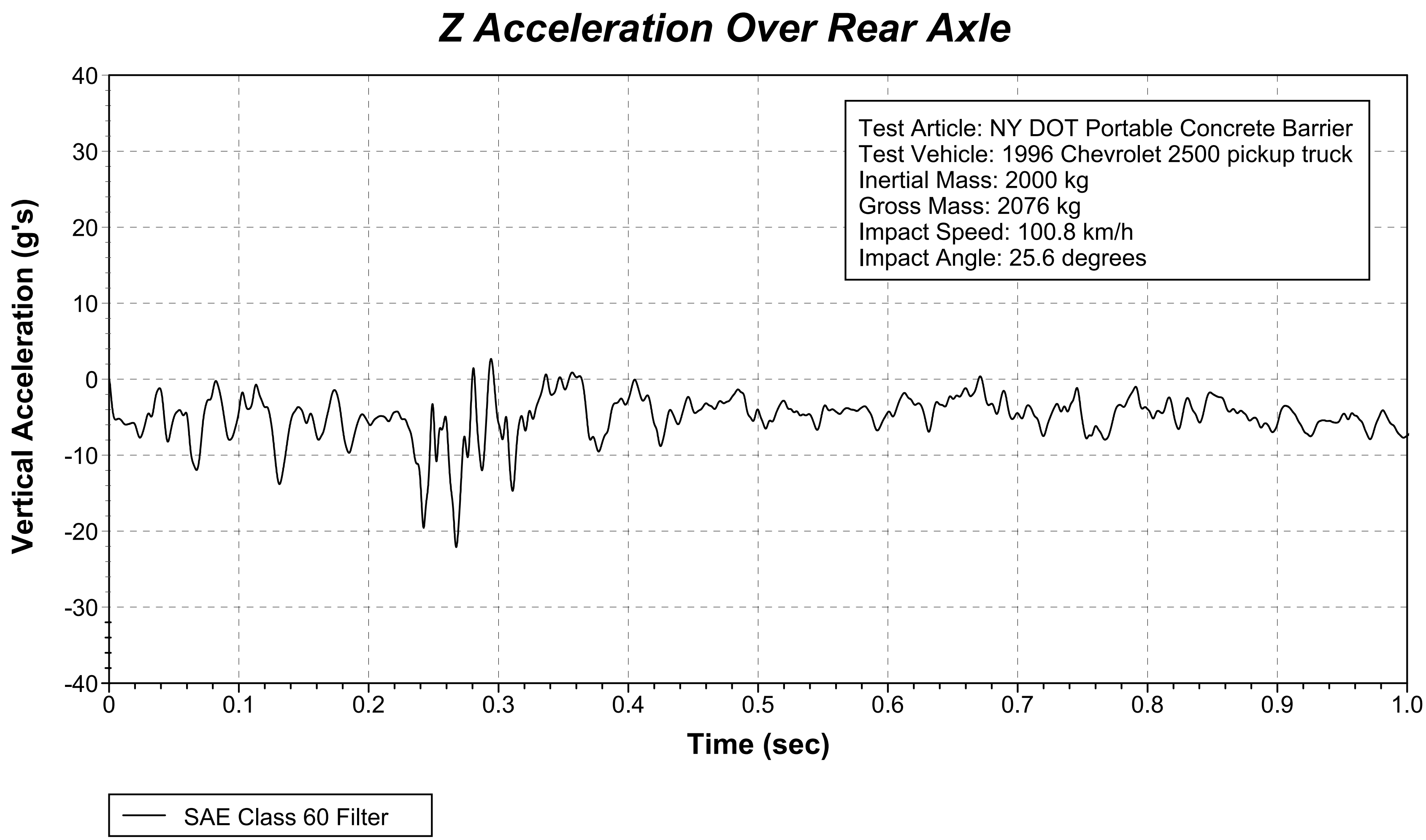


Figure 21. Vehicle vertical accelerometer trace for test 473220-14
(accelerometer located over rear axle).

REFERENCES

1. Part VI of the Manual on Uniform Traffic Control Devices (MUTCD), entitle *Standards and Guides for Traffic Controls for Street and Highway Construction, Maintenance, Utility and Incident Management Operations*, 1988 Edition, Revision 3, September 1993.

2. 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.

3. King K. Mak, Roger P. Bligh, Wanda L. Menges and Sandra K. Schoeneman, *NCHRP Report 350 Test 3-11 of the New York DOT Portable Concrete Barrier with I-Beam Connection*, Research Report 473220-7, Texas Transportation Institute, The Texas A&M University System, College Station, TX, February 1999.