CRASH TESTING AND EVALUATION OF THE HIGH-TENSION CABLE GUARDRAIL AT HIGH IMPACT ANGLE

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

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KEY WORDS

Guardrail, longitudinal barrier, cable rail, crash testing, roadside safety

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16. Abstract

High tension cable median barriers are being used extensively across the U.S. These barriers are often installed in wide medians. This may allow errant vehicles to approach the barrier at higher impact angles than are recommended in *NCHRP Report 350* for evaluation of longitudinal barriers. An understanding of the barrier performance (i.e. vehicle containment, stability, and expected cable deflection) at higher impact angles may provide information that will assist designers in placement of the barrier.

The objective of this project is to evaluate the crash performance of high tension cable median barriers when subjected to a 2000 kg pickup impacting the system at 100 km/h and 45 degrees. This test will determine the performance characteristics of high tension cable barrier when struck under excessive impact conditions. The results may be used to develop cable barrier placement guidelines.

The high-tension cable barrier, when impacted at 44.9 degrees, did redirect the vehicle but did not contain the vehicle. The vehicle pulled down and rode over the cables. The vehicle remained upright during the collision event, however, after loss of contact with the barrier, the vehicle rolled 90 degrees, then righted itself and came to rest upright.

17. Key Words	18. Distribution Statement
Guardrail, longitudinal barrier, cable rail, crash testing, roadside safety	Copyrighted. Not to be copied or reprinted without consent from WsDOT.

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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 millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		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		
		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 degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°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	35.314	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 degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°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 March 2003)

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INTRODUCTION

PROBLEM

High tension cable median barriers are being used extensively across the U.S. The basis for full-scale crash testing in National Cooperative Highway Research Program (NCHRP) *Report 350* assumes an encroachment angle near the edge of the road. These barriers are often installed in wide medians. This may allow errant vehicles to approach the barrier at higher impact angles than are recommended in *NCHRP Report 350* for evaluation of longitudinal barriers. An understanding of the barrier performance (i.e. vehicle containment, stability, and expected cable deflection) at higher impact angles may provide information that will assist designers in placement of the barrier.

BACKGROUND

A number of high tension cable median barriers have been successfully tested at both Test Level 3 (TL-3) and Test Level 4 (TL-4) under *NCHRP Report 350*. TL-3 includes a test with a 2000 kg (4409 lb) pickup impacting the system at 100 km/h (62.1 mi/h) and 25 degrees. TL-4 adds a test with an 8000 kg (17,637 lb) single-unit truck impacting the system at 80 km/h (49.7 mi/h) and 15 degrees. The systems have a variety of post configurations and post spacing. While there is some variation on the cable strength and installed modulus of elasticity, overall dimensions and construction are 19 mm (0.75 in), 3 x 7 wire ropes.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this project is to evaluate the crash performance of high tension cable median barriers when subjected to a 2000 kg (4409 lb) pickup impacting the system at 100 km/h (62.1 mi/h) and 45 degrees. This will determine the performance characteristics of high tension cable barrier when struck under excessive impact conditions. The results may be used to develop cable barrier placement guidelines.

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 the placement of the high-tension cable barrier is along the edge of a wide out-of-service runway apron. The apron consists of an unreinforced jointed concrete pavement in 3.8 m by 4.6 m (12.5 ft by 15 ft) blocks nominally 203-305 mm (8-12 in) deep. The aprons and runways are over 50 years old and the joints have some displacement, but are otherwise flat and level.

Test Article – Design and Construction

The high-tension cable barrier constructed for testing was the Trinity Cable Safety System (CASS), which uses three cables supported by C-channel support posts fabricated from ASTM A1011 SS Grade 36 Type 1 steel. Post spacing was 5.0 m (16.4 ft) in the length-of-need. Anchorage of the cables was achieved using a cable terminal system with the Cable Release Posts (CRP) anchored in 457 mm (18 in) diameter, 1524 mm (60 in) deep reinforced concrete footings. The system was tensioned to 24 kN (5395 lb) for the crash test.

The 1200 mm long galvanized 100x50x4 mm C-channel, mild steel support posts were inserted in socketed concrete foundations. Sockets were fabricated from steel plate 127 mm x 76 mm x 3 mm (5 in x 3 in x 0.125 in) and were 381 mm (15 in) long. The sockets were cast inside 305 mm (12.0 in) diameter, 762 mm (30.0 in) deep concrete footings that were cast in place. As can be seen in figure 1, the upper central portion of the post web has been removed for placement of the cables. The bottom cable rests in the bottom of the slot, a 51x89x20 mm (2.0x3.5x0.75 in) black plastic spacer block is then inserted to support the second cable. A rectangular stainless steel strap is placed around the post above the second cable. A second plastic spacer block is inserted above the second cable to support the top cable.

The 19 mm (0.75 in) cables are pre-stretched 3x7 strand with swaged threaded fittings on each end. Turnbuckles are placed between adjacent rope segments for tensioning. Cable mounting heights are 530 mm (20.9 in), 640 mm (25.25 in), and 750 mm (29.5 in) above ground.

Details of the installation are shown in figures 1 through 5, and photographs of the installation are shown in figure 6.

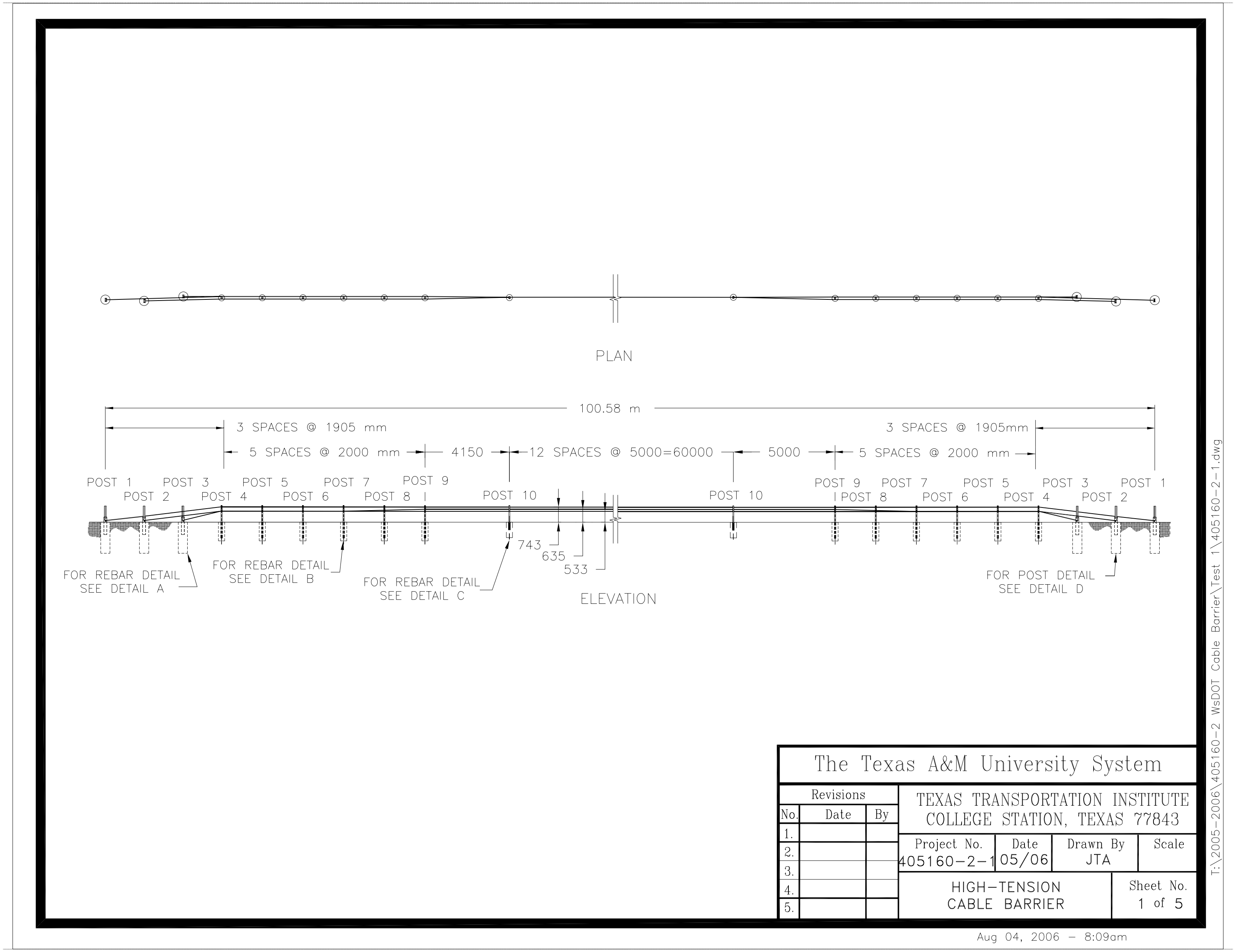


Figure 1. High-tension cable barrier – layout.

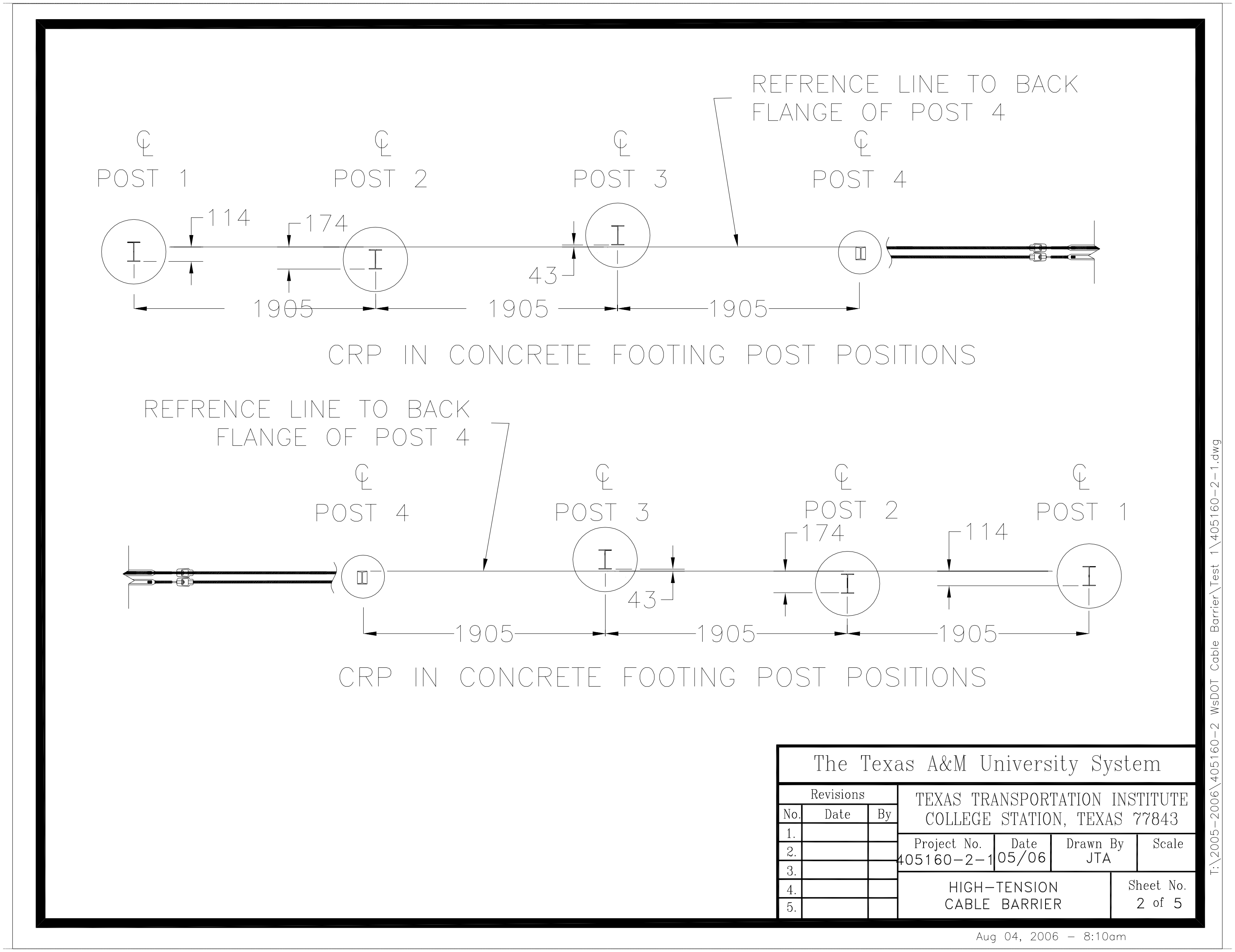


Figure 2. High-tension cable barrier – terminal layout.

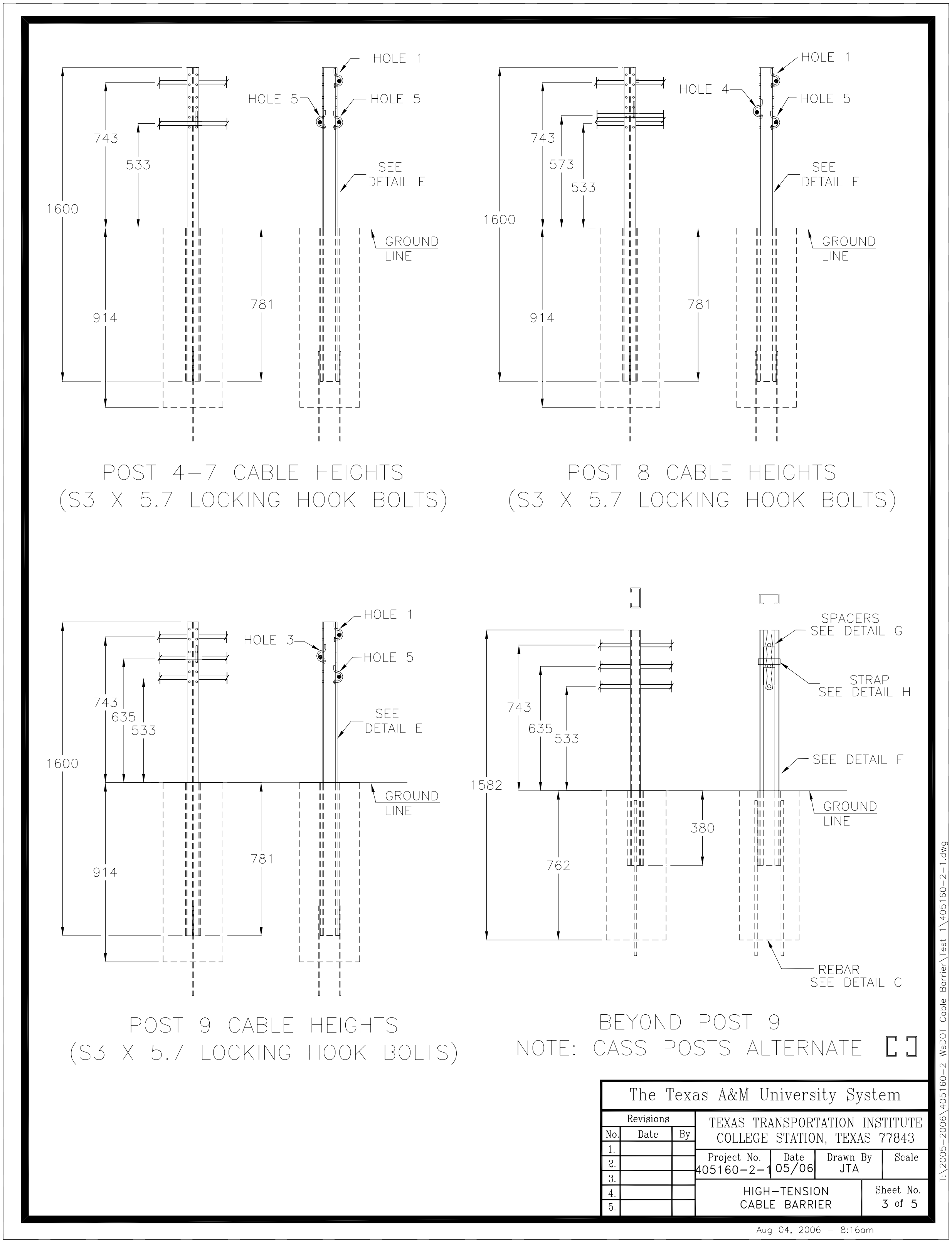


Figure 3. High-tension cable barrier – post height details.

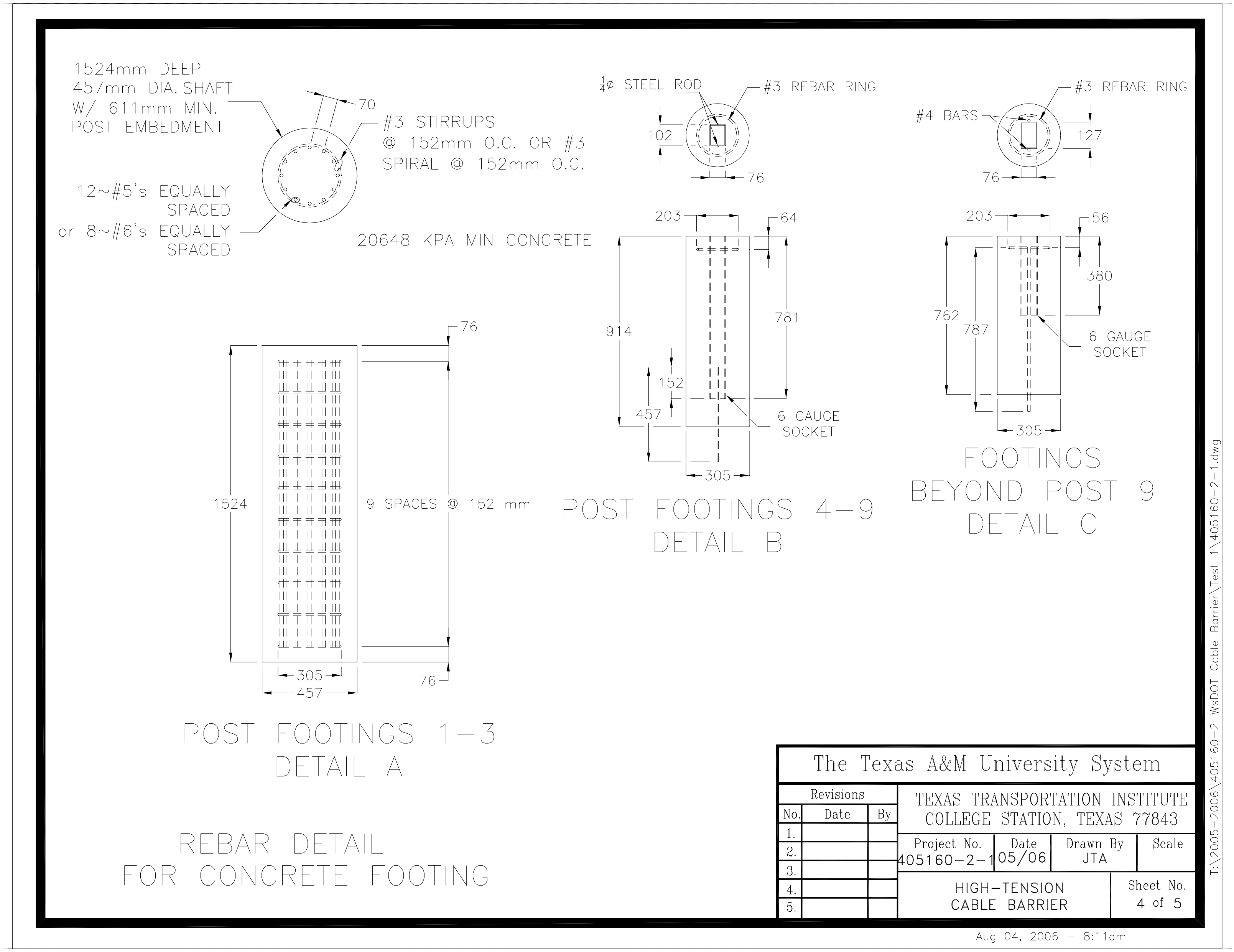


Figure 4. High-tension cable barrier – footing details.

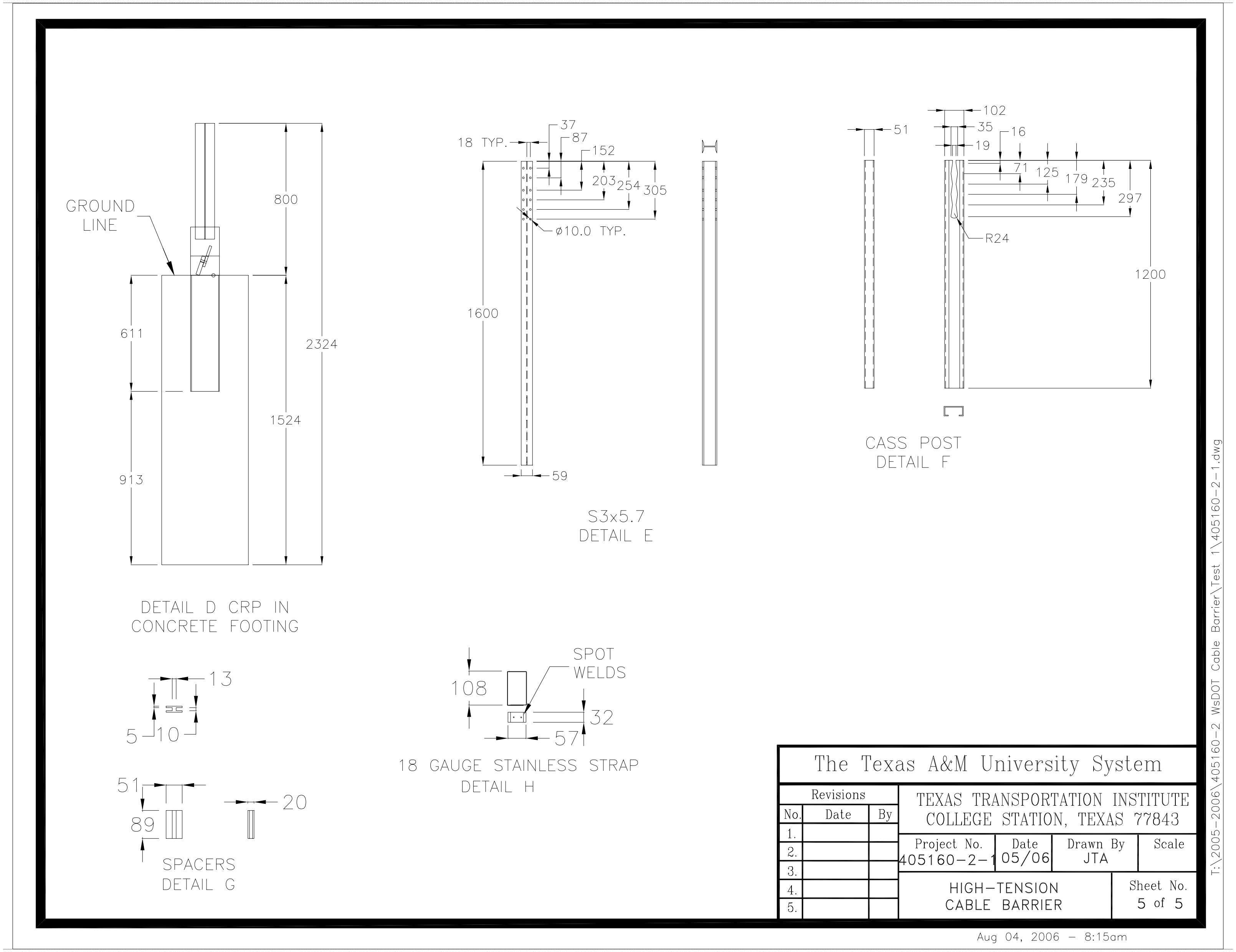


Figure 5. High-tension cable barrier – post details.

Figure 6. High-tension cable barrier prior to testing at 45 degrees.

Test Conditions

The objective of this project is to evaluate the crash performance of high tension cable median barriers when subjected to a 2000 kg (4409 lb) pickup impacting the system at 100 km/h (62.1 mi/h) and 45 degrees. This will determine the performance characteristics of high tension cable barrier when struck under excessive impact conditions. The target impact point was at a post at the one-third point.

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Appendix A presents brief descriptions of these procedures.

Evaluation Criteria

The crash test 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.

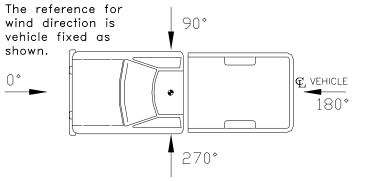
CRASH TEST 405160-2-1 (*NCHRP REPORT 350* TEST NO. 3-11 AT 45 DEGREES)

Test Vehicle

A 2000 Chevrolet 2500 pickup truck, shown in figures 7 and 8, was used for the crash test. Test inertia weight of the vehicle was 2117 kg (4667 lb), and its gross static weight was 2193 kg (4835 lb). The height to the lower edge of the vehicle front bumper was 415 mm (16.3 in), and the height to the upper edge of the front bumper was 635 mm (25.0 in). Additional dimensions and information on the vehicle are given in appendix B, figure 14. The vehicle was directed into the installation using the 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 May 11, 2006. Rainfall amounts of 1.22 inches on May 6, 0.15 inch on May 5, and 0.23 inch on May 4 were recorded for the ten days prior to the test. Moisture content of the *NCHRP Report 350* soil in which the test article was installed was 6.5 percent. Weather conditions at the time of testing were: Wind speed: 12 km/h (7.5 mi/h); wind direction: 315 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); temperature: 22 ºC (72 ºF).



Impact Description

The 2193 kg (4835 lb) pickup truck, traveling at a speed of 101.1 km/h (62.8 mi/h), impacted the high-tension cable barrier at post 12 at an impact angle of 44.9 degrees. At approximately 0.058 s after impact, the top cable pulled out of the top of post 13, and at 0.066 s, the top cable pulled out of the top of post 11. By 0.083 s, the rear flange at the lower end of the wavy slot on post 13 deformed and released the middle cable. At 0.095 s, the top cable pulled out of the top of post 14, and at 0.122 s, the rear flange at the lower end of the wavy slot at post 14 deformed and released the middle cable. The vehicle began to redirect at 0.156 s. At 0.168 s, the rear flange at the lower end of the wavy slot at post 11 deformed and released the middle cable. The bottom cable pulled out of posts 13 and 14 at 0.227 s and 0.258 s, respectively. The middle cable rebounded off the vehicle at 0.415 s. At 0.534 s, the top cable reached a maximum deflection of 6.5 m before rebounding off the pickup. The vehicle lost contact with the top cable soon thereafter, continued to yaw counterclockwise, and subsequently rolled 90 degrees on to its right side. The vehicle then righted itself and came to rest 14.6 m (47.9 ft) toward field side behind post 20. Sequential photographs of the test period are shown in appendix C, figures 15 and 16.

Figure 7. Vehicle/installation geometrics for test 405160-2-1.

Figure 8. Vehicle before test 405160-2-1.

Damage to Test Article

Damage to the installation is shown in figures 9 and 10. All the restraining straps on the top of the wavy slot of the CASS posts failed during the test. Post 1 and 2 were disturbed, and no movement was noted at post 3. The top and bottom cables were separated from post 4 and all cables from post 5. The top cable only was separated from posts 6-9, and post 9 was leaning toward the field side 50 mm (2.0 in). The rear flange at the lower end of the wavy slot of post 10 was deformed toward the field side 90 degrees and all cables separated from the post. Post 11 was deformed toward field side about 15 degrees, the rear flange at the lower end of the wavy slot deformed 21 degrees, and the top and middle cables were separated from the post. Post 12 pulled out of the socket and was resting 19 m forward of the traffic face of the barrier. Posts 13-16 were deformed at ground line and pulled toward the field side 30 mm (1.2 in), with the rear flange at the lower end of the wavy slot deformed at 90 degrees and all cables separated from the post. Posts 17 and 18 were deformed at ground line and pulled toward the field side 30 mm (1.2 in), with the rear flange at the lower end of the wavy slot deformed at 90 degrees and the top and middle cables separated from the posts. Posts 19 and 20 were deformed at ground line and pulled toward the field side 250 mm (9.8 in) and 200 mm (7.9 in), respectively, with the rear flange at the lower end of the wavy slot deformed at 90 degrees and the top and middle cables separated from the posts. The rear flange at the lower end of the wavy slot at posts 21 and 22 was deformed 90 degrees and the top and middle cables separated from the posts. The top cable was separated from posts 23 through 27. The top and middle cable separated from post 28 and the post was pulled upstream 60 mm (2.4 in). Post 29 was disturbed only, and posts 30 and 31 were pulled upstream 20 mm (0.8 in) and 30 mm (1.2 in), respectively. Working width could not be determined. Maximum dynamic deflection of the cable barrier just prior to the vehicle exiting through the cable barrier was 6.5 m (21.3 ft).

Vehicle Damage

Damage to the vehicle is shown in figure 11. No structural damage was sustained by the pickup during the initial collision event. The front bumper, right front quarter panel, right door, right rear exterior bed were deformed and the right front tire and rim and right rear tire and rim were damaged from the initial collision event. During rollover, the left A-pillar and B-pillar and left front quarter panel deformed, and the right door glass shattered and windshield cracked. Maximum exterior crush to the vehicle was 260 mm (10.2 in) in the side plane at the right front corner at bumper height. Maximum occupant compartment deformation from the initial impact was 14 mm (0.6 in) in the lateral area across the floor pan (from kickpanel to kickpanel). Maximum occupant compartment deformation from the rollover event was 27 mm (1.1 in) in the diagonal distance between the lower edge of the A-pillar and the upper edge of the B-pillar on the left side. Photographs of the interior of the vehicle are shown in figure 12. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 2 and 3.

Figure 9. Vehicle trajectory path after test 405160-2-1.

Figure 10. Installation after test 405160-2-1.

Figure 11. Vehicle after test 405160-2-1.

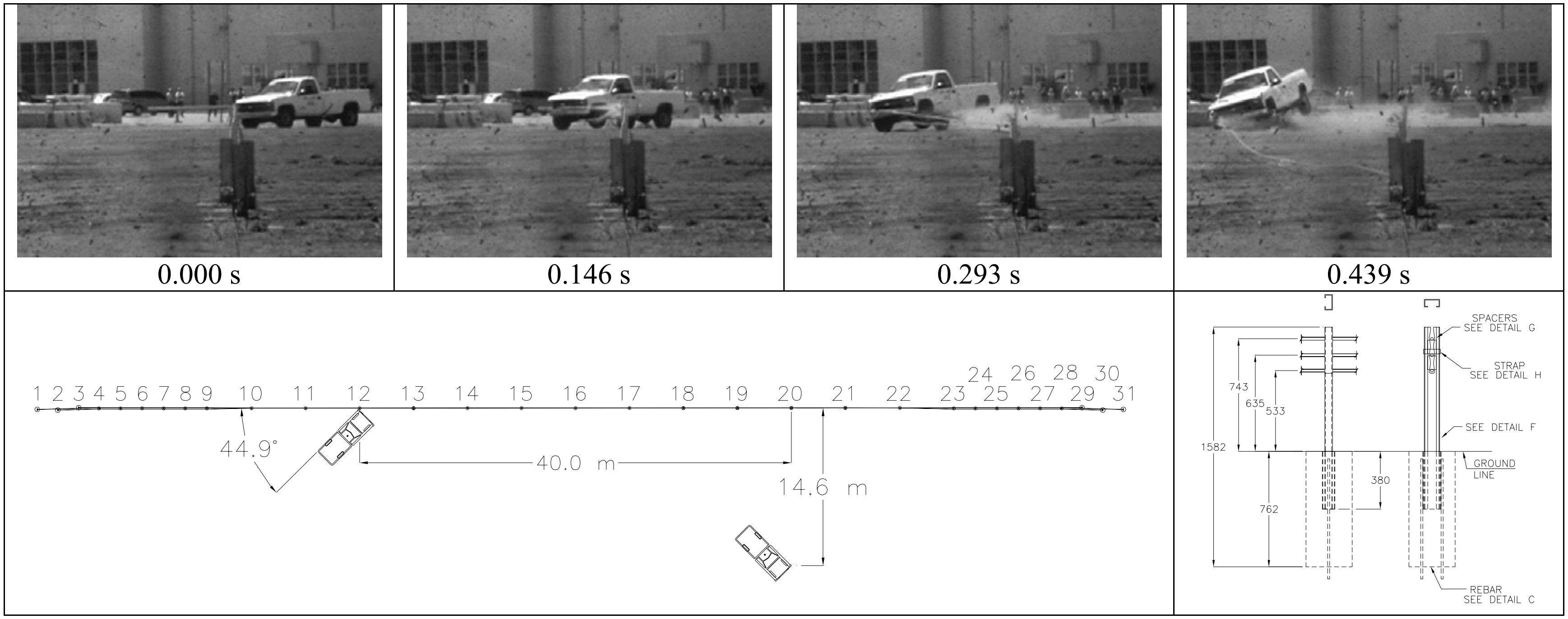
Before test

After test

Figure 12. Interior of vehicle for test 405160-2-1.

Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle center of gravity, were digitized to compute occupant impact velocity and ridedown accelerations. 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*. In the longitudinal direction, occupant impact velocity was 3.5 m/s (11.5 ft/s) at 0.244 s, maximum 0.010-s ridedown acceleration was -6.0 g's from 0.516 to 0.526 s, and the maximum 0.050-s average was -2.8 g's between 0.307 and 0.357 s. In the lateral direction, the occupant impact velocity was 2.8 m/s (9.2 ft/s) at 0.244 s, the highest 0.010-s occupant ridedown acceleration was -4.9 g's from 0.524 to 0.534 s, and the maximum 0.050-s average was -3.4 g's between 0.797 and 0.847 s. These data and other information pertinent to the test are presented in figure 13. Vehicle angular displacements and accelerations versus time traces are shown in appendix D, figures 17 through 23.



General Information	
Test Agency	Texas Transportation Institute
Test No.	405160-2-1
Date	05-11-2006
Test Article	
Type	Cable Barrier
Name	Trinity CASS
Installation Length (m)	100.6
Material or Key Elements	3-Cable Barrier System Supported By C-Channel Mild Steel Support Posts
Soil Type and Condition	Standard Soil, Dry
Test Vehicle	
Type	Production
Designation	2000P
Model	2000 Chevrolet C2500 Pickup Truck
Mass (kg)	
Curb	2155
Test Inertial	2117
Dummy	76
Gross Static	2193

Impact Conditions	
Speed (km/h)	101.1
Angle (deg)	44.9
Exit Conditions	
Speed (km/h)	N/A
Angle (deg)	N/A
Occupant Risk Values	
Impact Velocity (m/s)	
Longitudinal	3.5
Lateral	2.8
THIV (km/h)	15.1
Ridedown Accelerations (g's)	
Longitudinal	-6.0
Lateral	-4.9
PHD (g's)	6.1
ASI	0.41
Max. 0.050-s Average (g's)	
Longitudinal	-2.8
Lateral	-3.4
Vertical	2.1

Test Article Deflections (m)	
Dynamic	6.50
Permanent	N/A
Working Width	7.60
Vehicle Damage	
Exterior	
VDS	01RFQ1
CDC	01FREW1
Max. Exterior Vehicle Crush (mm)	260
Interior	
OCDI	LF0000000
Max. Occupant Compartment Deformation (mm)	27
Post-Impact Behavior	
(during 1.0 sec after impact)	
Max. Yaw Angle (deg)	-123
Max. Pitch Angle (deg)	-11
Max. Roll Angle (deg)	34
(vehicle subsequently rolled 90°)	

Figure 13. Summary of results for *NCHRP Report 350* test 3-11 at 45 degrees on the high-tension cable barrier.

SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

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

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 high-tension cable barrier, when impacted at 44.9 degrees, did redirect the vehicle but did not contain the vehicle. The vehicle pulled down and rode over the cables. (FAIL)

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: One of the posts pulled out of the ground and was thrown 19 m forward of the traffic face of the rail. This post did not penetrate or show potential for penetrating the occupant compartment, nor to present hazard to others in the area. Maximum occupant compartment deformation from the initial impact was 14 mm (0.6 in) in the lateral area across the floor pan (from kickpanel to kickpanel). Maximum occupant compartment deformation from the rollover event was 27 mm (1.1 in) in the diagonal distance between the lower edge of the A-pillar and the upper edge of the B-pillar on the left side. (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 the collision event, however, after loss of contact with the barrier, the vehicle rolled 90 degrees, then righted itself and came to rest upright. (FAIL)

Vehicle Trajectory

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

Result: The vehicle came to rest upright 14.6 m (47.9 ft) on the field side of the cable barrier. (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.*

Result: Longitudinal occupant impact velocity was 3.5 m/s, and longitudinal ridedown acceleration was -6.0 g. (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.*

Result: Exit angle at loss of contact was not obtainable. (N/A)

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: (2)

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*

One post pulled up and was thrown 19 m forward of the traffic face of the rail, but did not present threat to others as it remained low to the ground.

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*

CONCLUSIONS

The high-tension cable barrier, when impacted at 44.9 degrees, did redirect the vehicle but did not contain the vehicle. The vehicle pulled down and rode over the cables. The vehicle remained upright during the collision event, however, after loss of contact with the barrier, the vehicle rolled 90 degrees, then righted itself and came to rest upright.

Table 1. Performance evaluation summary for *NCHRP Report 350* test 3-11 at 45 degrees on the high-tension cable barrier.

Test Agency: Texas Transportation Institute Test No.: 405160-2-1 05-11-2006

***NCHRP Report 350* Test 3-11 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 high-tension cable barrier, when impacted at 44.9 degrees, did redirect the vehicle but did not contain the vehicle. The vehicle pulled down and rode over the cables.	Fail
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.*	One of the posts pulled out of the ground and was thrown 3 m forward of the traffic face of the rail. This post did not penetrate or show potential for penetrating the occupant compartment, nor to present hazard to others in the area. Maximum occupant compartment deformation from the initial impact was 14 mm from kickpanel to kickpanel. Maximum occupant compartment deformation from the rollover event was 27 mm in the diagonal distance between the lower edge of the A-pillar and the upper edge of the B-pillar on the left side.	Pass
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 event, however, after loss of contact with the barrier, the vehicle rolled 90 degrees, then righted itself and came to rest upright.	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 upright 14.6 m on the field side of the cable barrier.	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 3.5 m/s, and longitudinal ridedown acceleration was -6.0 g.	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 not obtainable.	N/A*

*Criterion K and M are preferable, not required.

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. Federal Highway Administration Memorandum, from the Director, Office of Engineering, entitled: “ACTION: Identifying Acceptable Highway Safety Features,” dated July 25, 1997.

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 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 ±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 (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 (IRIG), FM/FM telemetry link for recording and for display. 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 TEAC® instrumentation data recorder. After the test, the data are played back from the TEAC® recorder 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 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-milliseconds (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

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 820C 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 flashbulb 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 BetaCam, a VHS-format video camera and recorder, and still cameras recorded and documented 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 two-to-one 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: 5-11-2006 Test No.: 405160-2-1 VIN No.: 1GCGC24R4YR192198

Year: 2000 Make: Chevrolet Model: C2500

Tire Inflation Pressure: Odometer: 121720 Tire Size: 245 75 R16

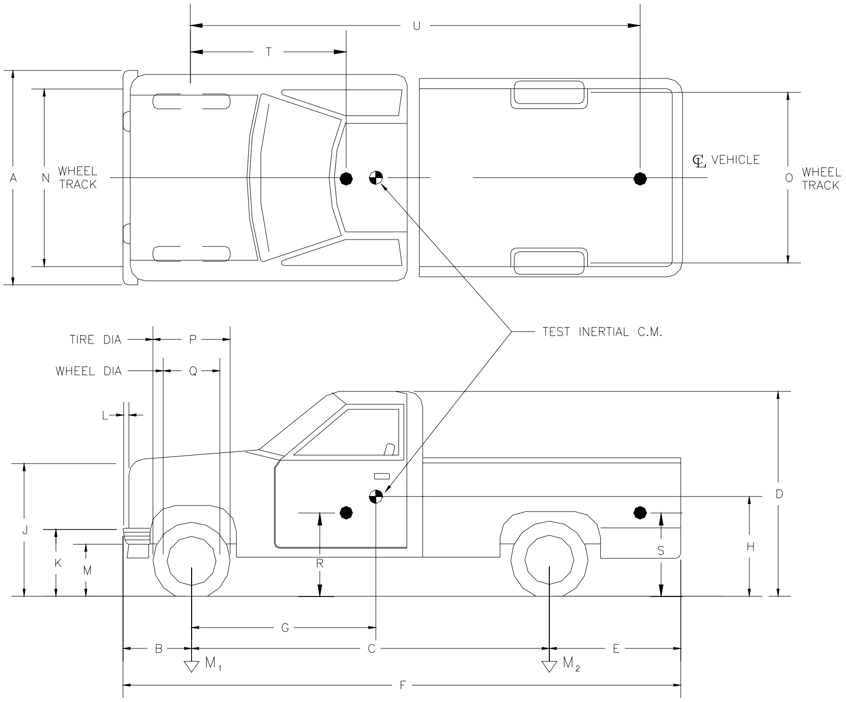
Describe any damage to the vehicle prior to test:

- ● Denotes accelerometer location.

NOTES:

Engine Type: V-8
Engine CID: 5.7 L
Transmission Type:
____ Auto
X Manual
Optional Equipment:

Dummy Data:
Type:
Mass:
Seat Position:



Geometry (mm)

A	1880	E	1310	J	1038	N	1590	R	750
B	810	F	5470	K	635	O	1610	S	900
C	3350	G	1449.5	L	70	P	725	T	1460
D	1820	H		M	415	Q	440	U	3360

Mass (kg)	Curb	Test Inertial	Gross Static
M_1	1214	1201	1246
M_2	941	916	947
M_{Total}	2155	2117	2193

Mass Distribution (kg): LF: 595 RF: 606 LR: 440 RR: 476

Figure 14. Vehicle properties for test 405160-2-1.

Table 2. Exterior crush measurements for test 405160-2-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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	Above bumper	900	160	700	30	40	50	80	140	160	-550
2	Above bumper	900	260	1100	0	20	N/A	N/A	150	260	+1620

[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).

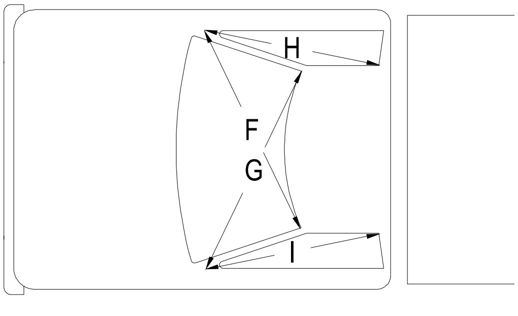
***Measure and document on the vehicle diagram the location of the maximum crush.

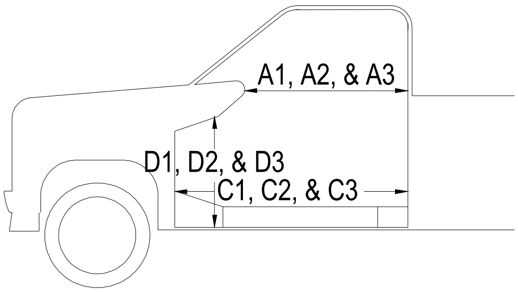
Note: Use as many lines/columns as necessary to describe each damage profile.

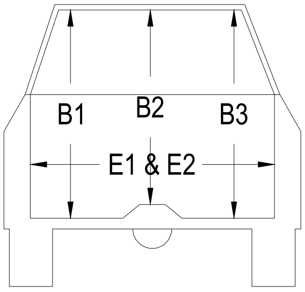
Table 3. Occupant compartment measurements for test 405160-2-1.

Truck

Occupant Compartment Deformation



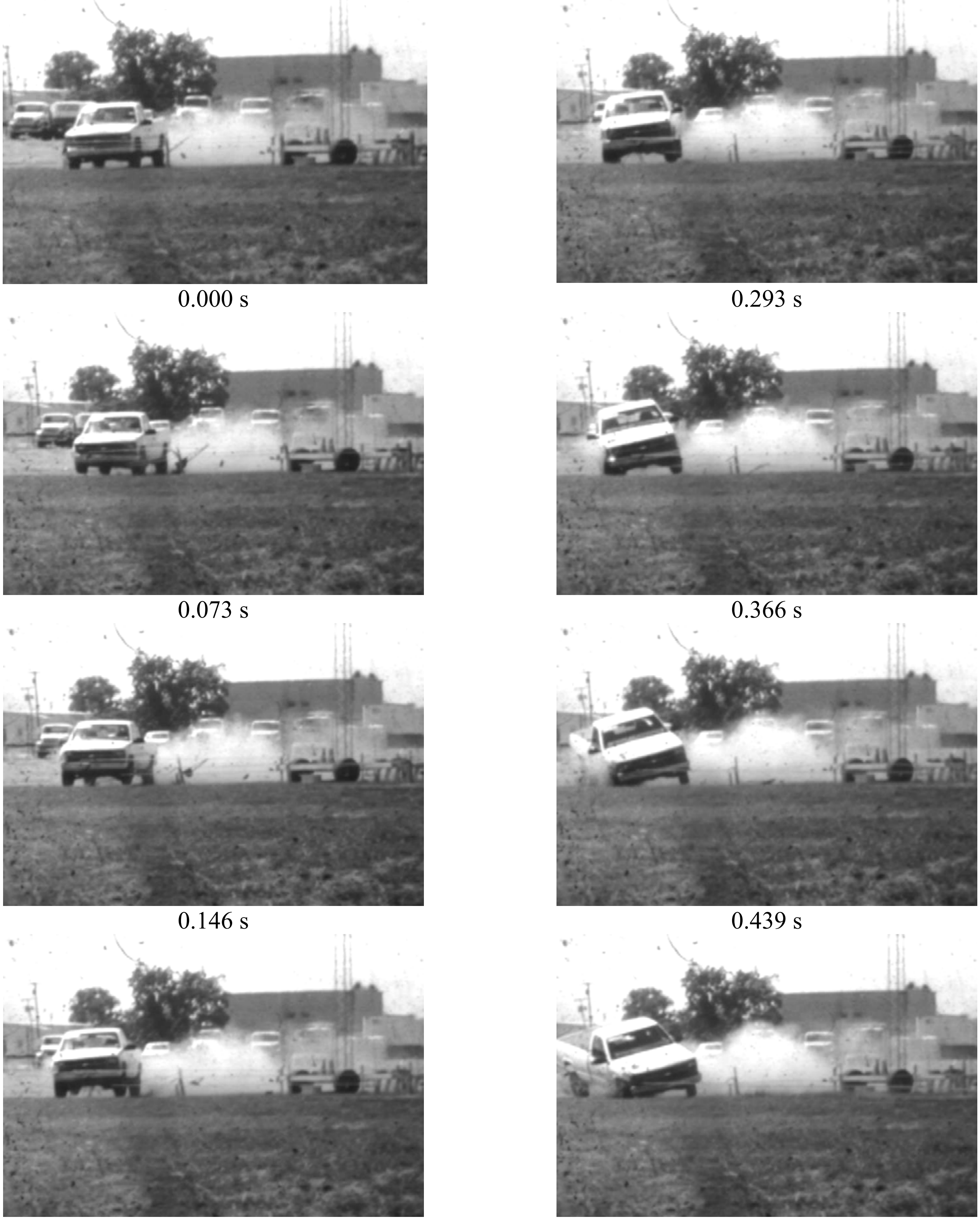




	BEFORE (mm)	AFTER (mm)
A1	872	872
A2	942	942
A3	934	930
B1	1077	1077
B2	949	949
B3	1070	1083
C1	1370	1370
C2		
C3	1361	1361
D1	327	327
D2	158	158
D3	311	313
E1	1588	1593
E2	1588	1595
F	1470	1465
G	1470	1456
H	1061	1061
I	1061	1034
J*	1523	1506

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

APPENDIX C. SEQUENTIAL PHOTOGRAPHS



0.000 s

0.073 s

0.146 s

0.220 s

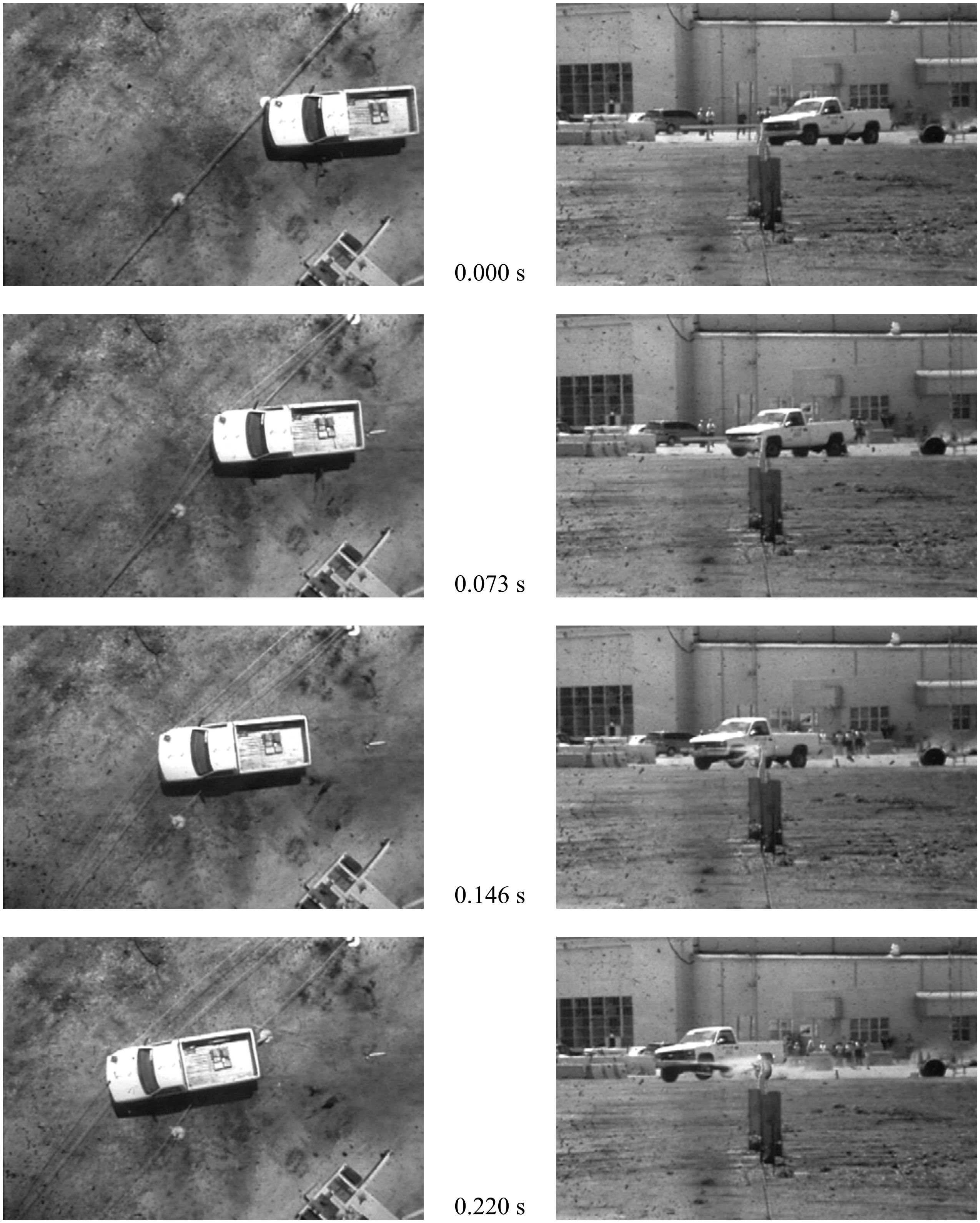
0.293 s

0.366 s

0.439 s

0.512 s

Figure 15. Sequential photographs for test 405160-2-1
(rear view).



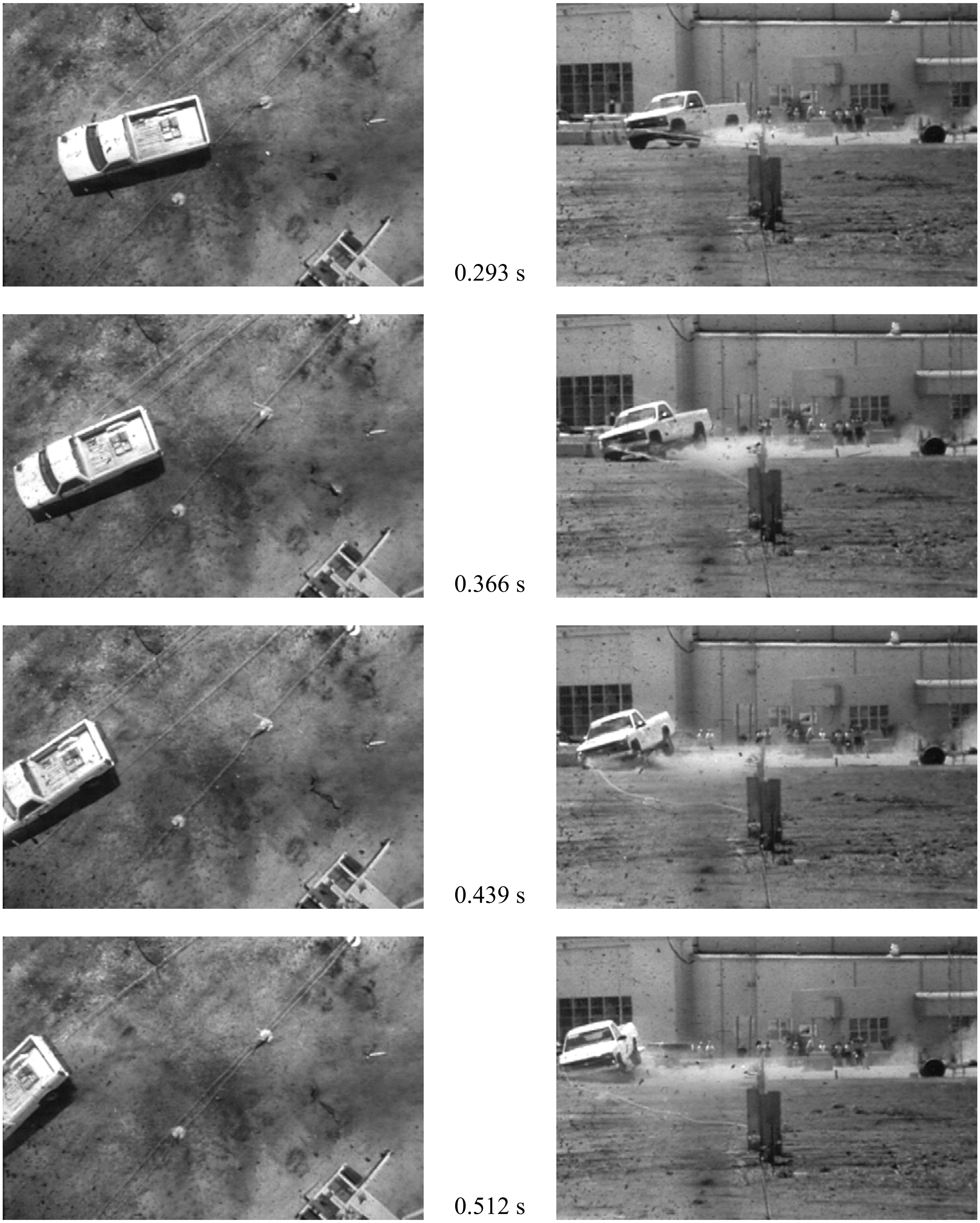
0.000 s

0.073 s

0.146 s

0.220 s

Figure 16. Sequential photographs for test 405160-2-1
(overhead and frontal views).



0.293 s

0.366 s

0.439 s

0.512 s

Figure 16. Sequential photographs for test 405160-2-1
(overhead and frontal views) (continued).

APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS

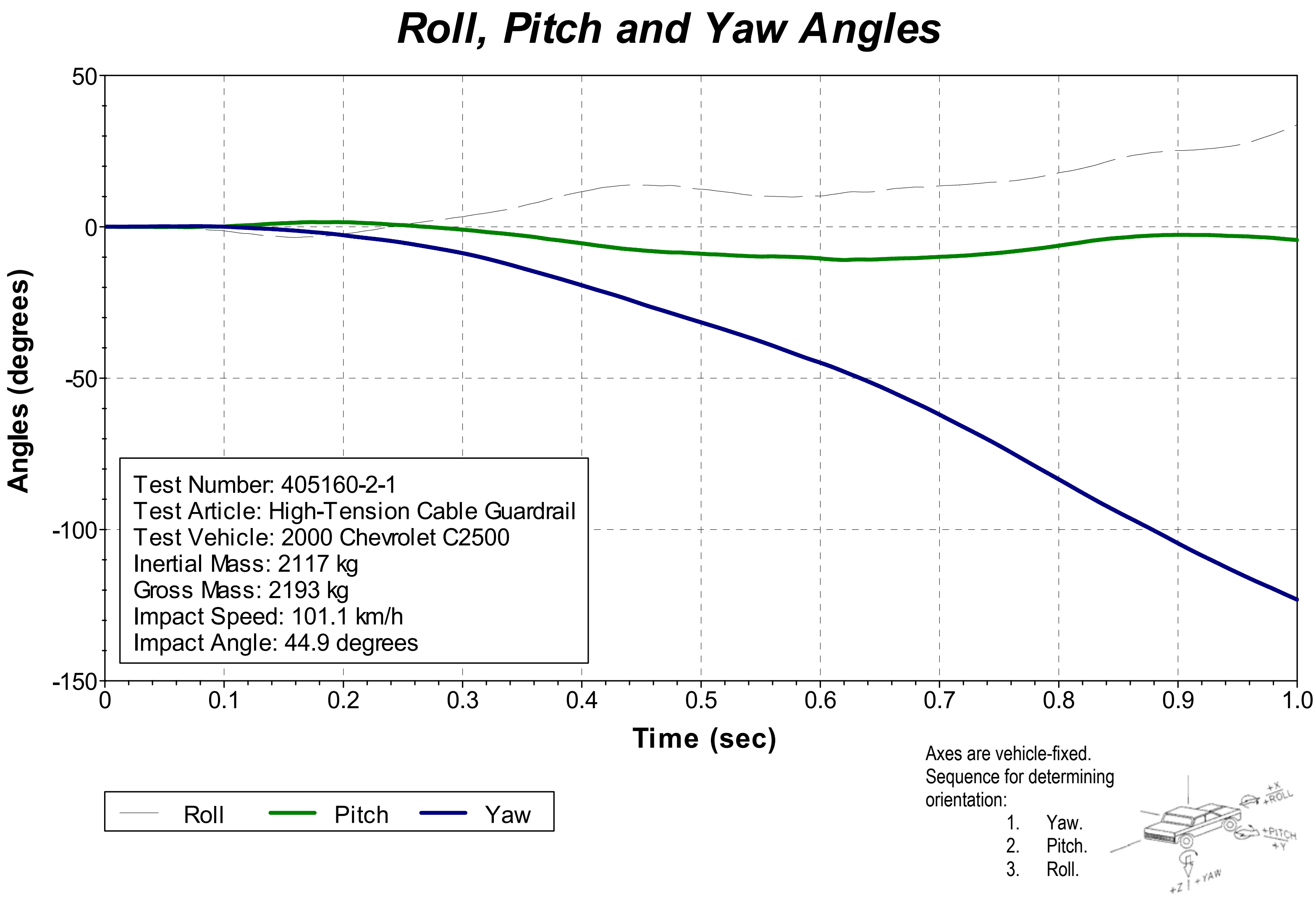


Figure 17. Vehicle angular displacements for test 405160-2-1.

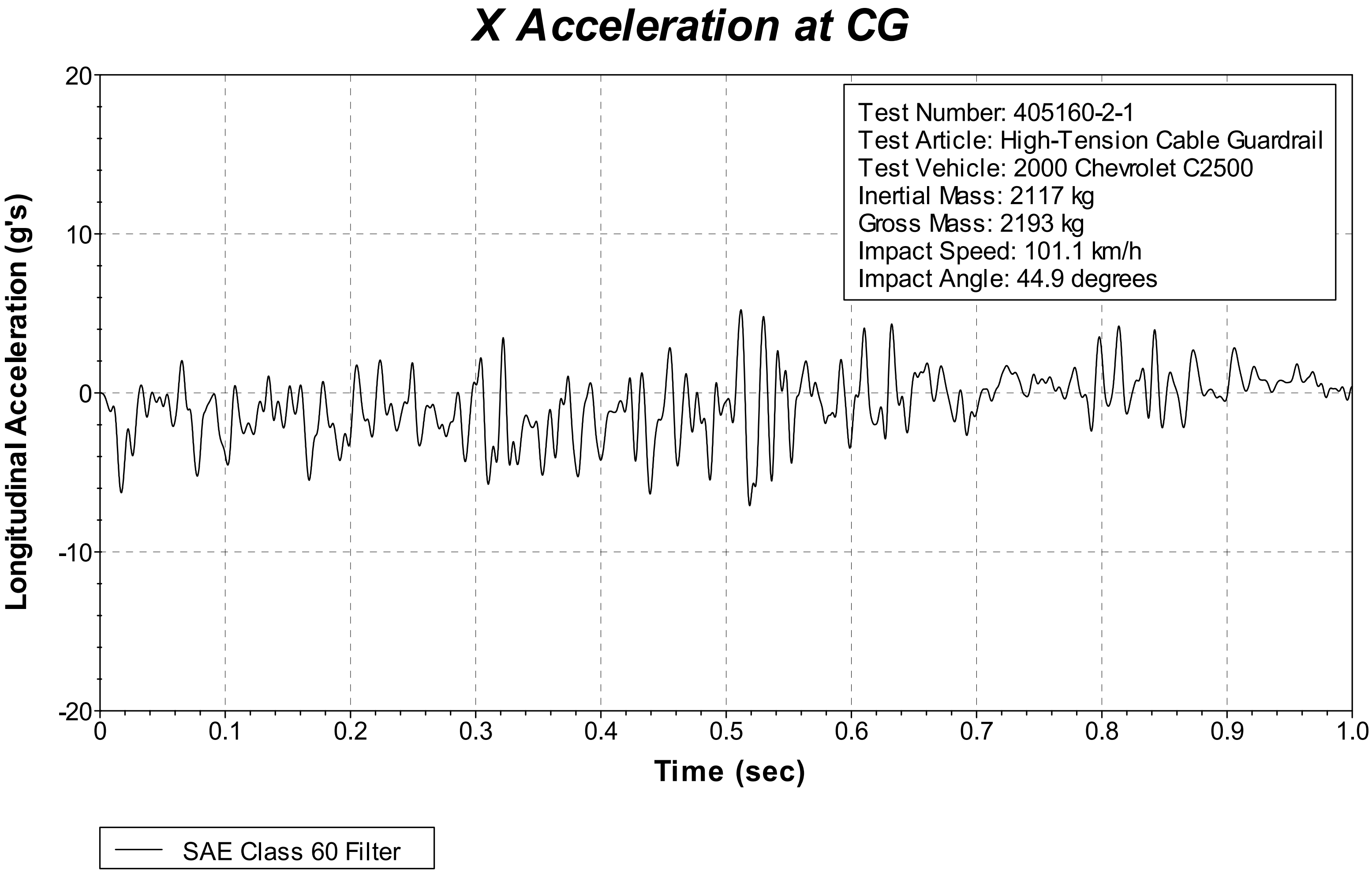


Figure 18. Vehicle longitudinal accelerometer trace for test 405160-2-1
(accelerometer located at center of gravity).

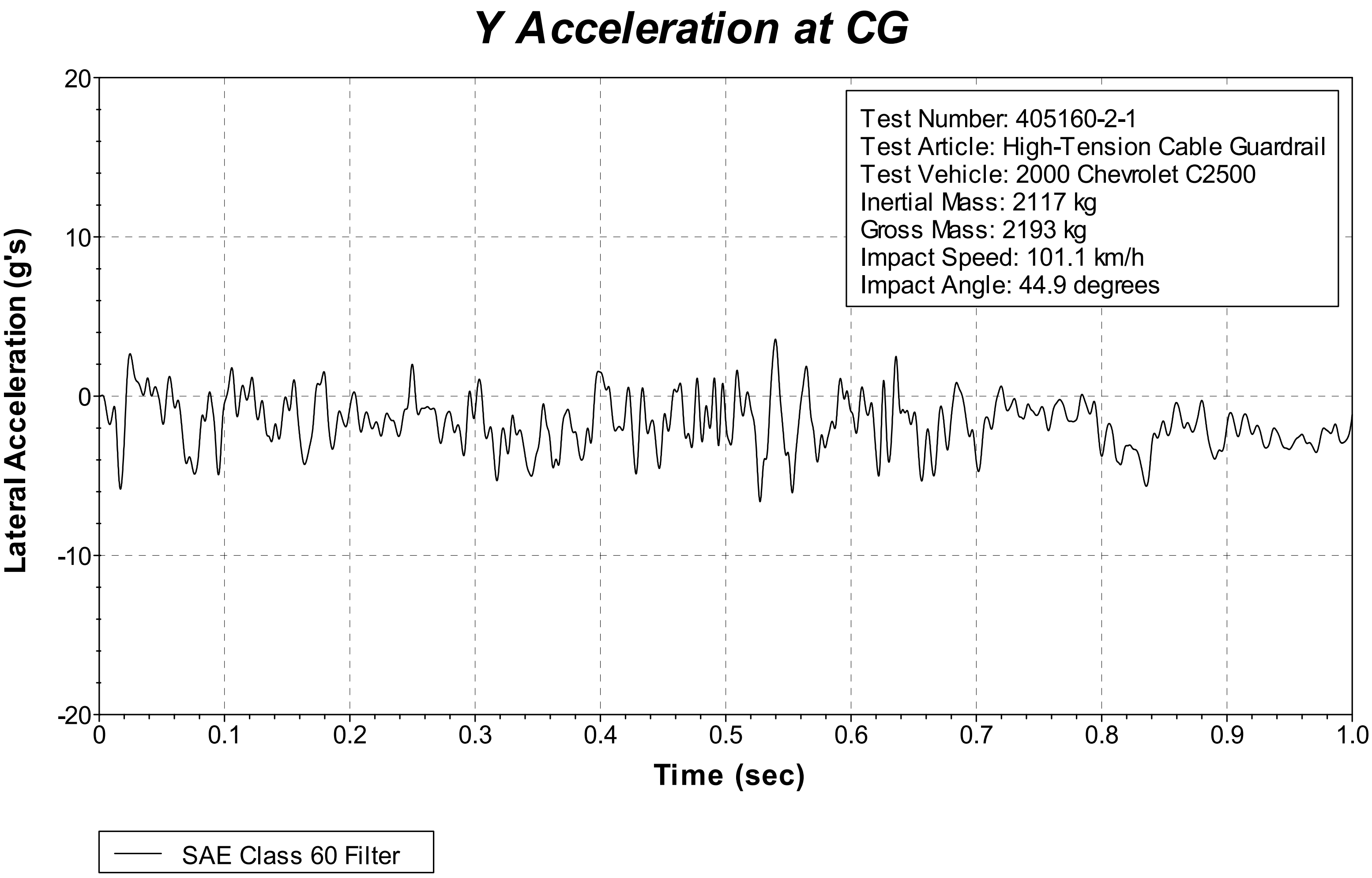


Figure 19. Vehicle lateral accelerometer trace for test 405160-2-1 (accelerometer located at center of gravity).

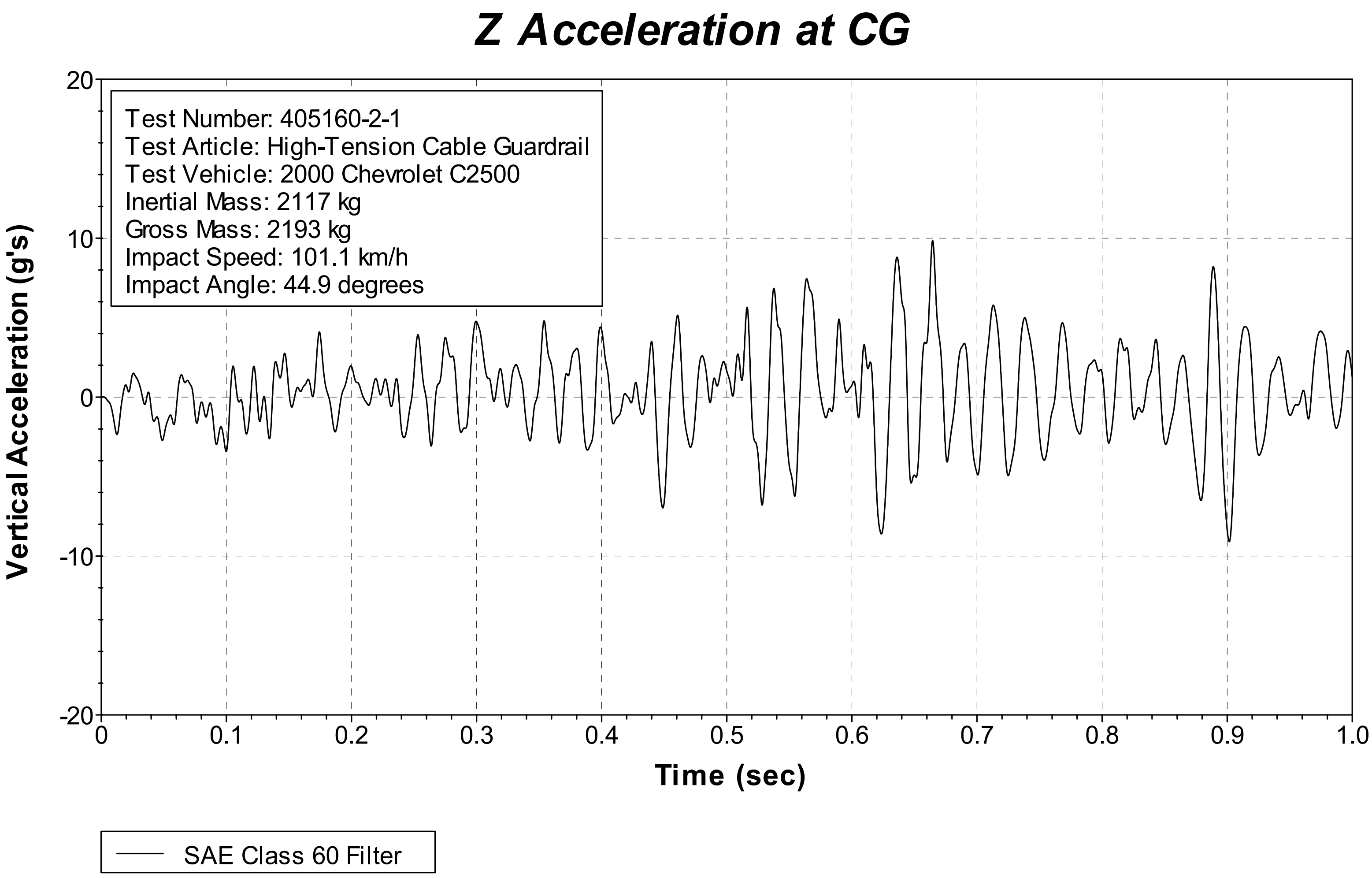


Figure 20. Vehicle vertical accelerometer trace for test 405160-2-1
(accelerometer located at center of gravity).

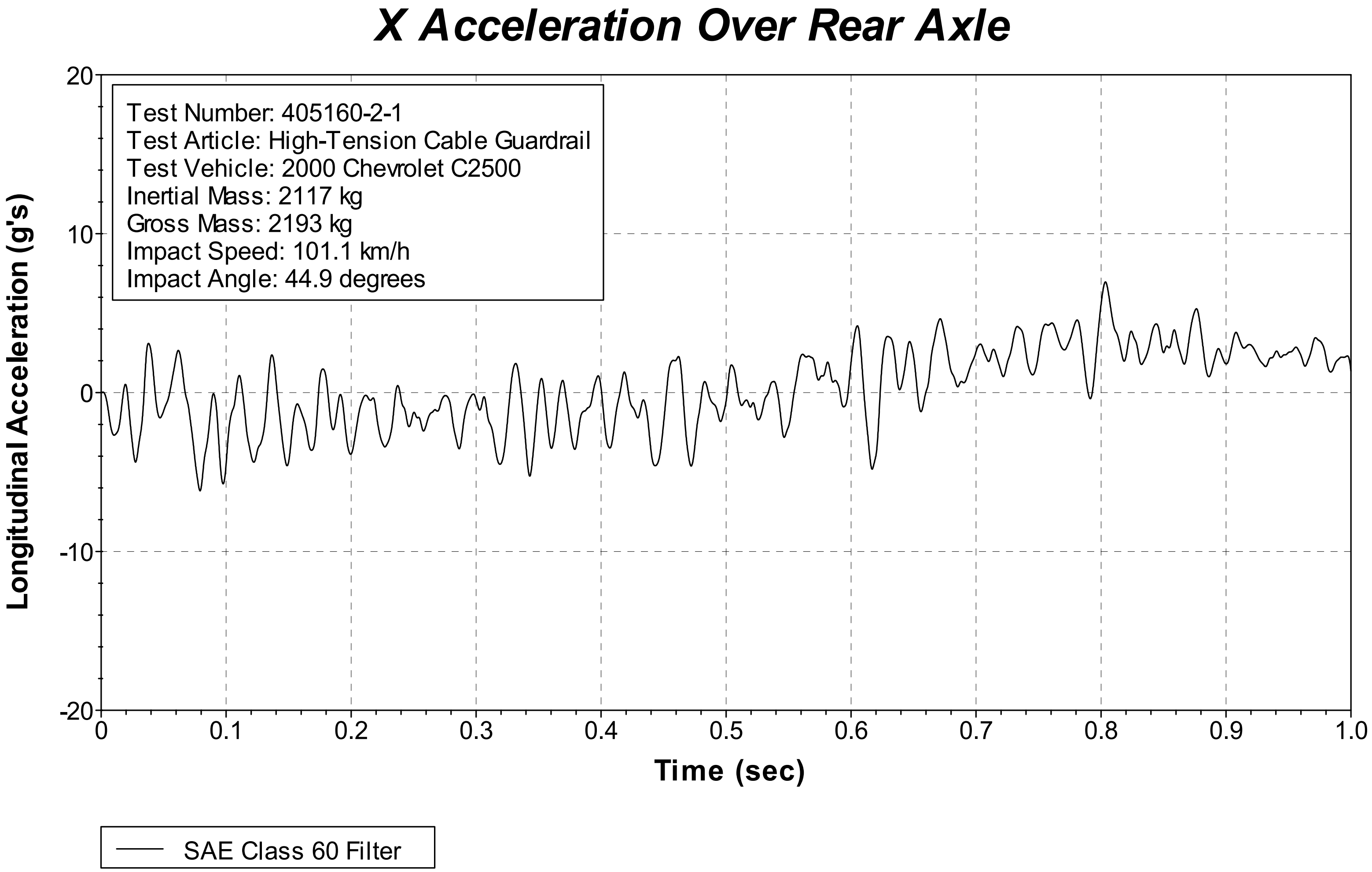


Figure 21. Vehicle longitudinal accelerometer trace for test 405160-2-1
(accelerometer located over rear axle).

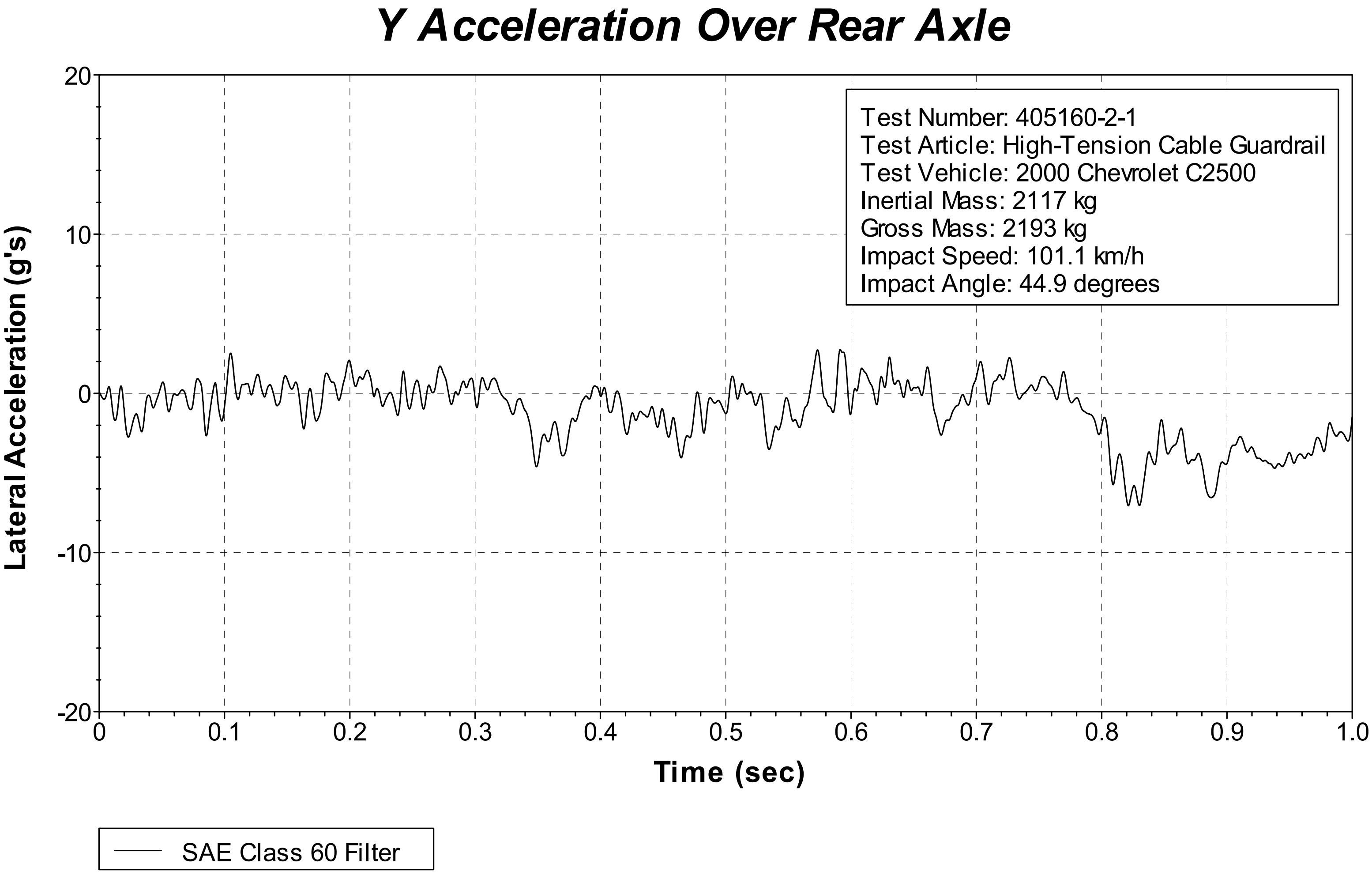


Figure 22. Vehicle lateral accelerometer trace for test 405160-2-1
(accelerometer located over rear axle).

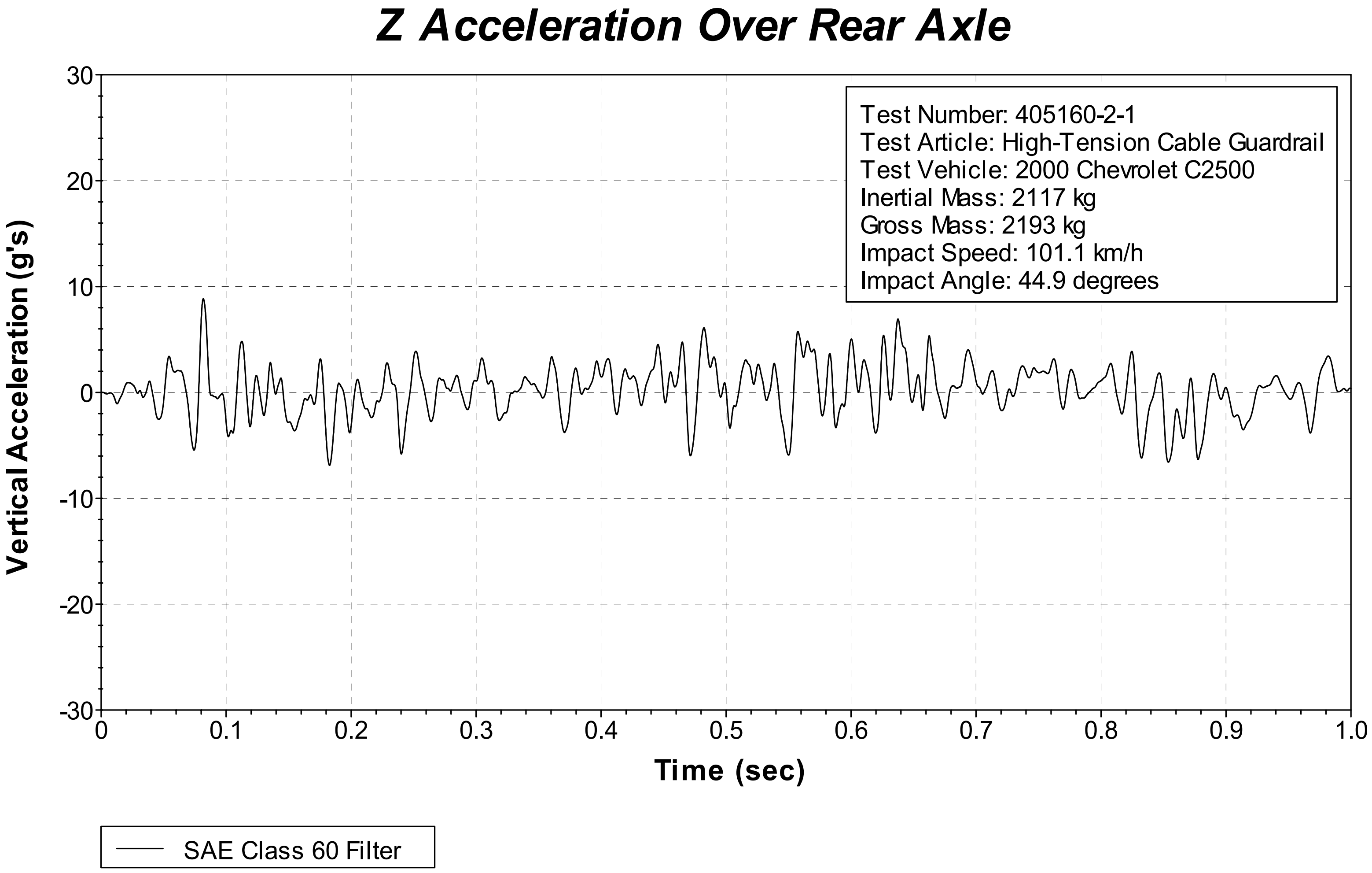


Figure 23. Vehicle vertical accelerometer trace for test 405160-2-1
(accelerometer located over rear axle).