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NCHRP REPORT 350 TEST 3-11 OF THE LONG-SPAN GUARDRAIL WITH 5.7 M CLEAR SPAN AND NESTED W-BEAMS OVER 11.4 M

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KEY WORDS

Guardrail, longitudinal barrier, culvert, w-beam, nested, long-span, crash testing, roadside safety.

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16. Abstract <p>The objective of this project was to develop a long-span guardrail design that meets <i>NCHRP Report 350</i> evaluation criteria and is less expensive to construct than the existing design.</p> <p>The researchers reviewed design details of the long-span guardrails previously developed, especially the design presented by Mak, to evaluate expected behavior of the guardrail when subjected to <i>NCHRP Report 350</i> tests. Design features that have been found to be important in terms of capacity of the guardrail to contain and redirect a vehicle are the structural strength and geometrics of the guardrail. Lateral stiffness of the guardrail system is the primary design feature that determines maximum deflection of the guardrail during a collision and changes in lateral stiffness of the guardrail system along its length are the key features influencing pocketing of the vehicle.</p> <p>The BARRIER VII computer program was used to evaluate expected performance of the proposed design in <i>NCHRP Report 350</i> tests. This program models a collision in two dimensions with a simple characterization of a vehicle and a detailed characterization of the guardrail. It was used to evaluate the expected deflections of the barrier and to predict any potential of the barrier to allow any unacceptable pocketing of the vehicle.</p> <p>Reported herein are the details and results of the full-scale crash test performed on the long-span guardrail. The rail element ruptured and allowed the vehicle to penetrate the rail system. The vehicle subsequently rolled onto its side. Therefore, the rail failed evaluation criteria for <i>NCHRP Report 350</i> test 3-11. The abrupt change in stiffness of the rail element where it changes from two layer of W-beam (nested) to a single layer may have contributed to rupture of the single layer rail element.</p>			
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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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TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
INTRODUCTION	1
PROBLEM.....	1
BACKGROUND	1
OBJECTIVES/SCOPE OF RESEARCH	1
TECHNICAL DISCUSSION	3
TEST PARAMETERS.....	3
Test Facility	3
Test Article – Design and Construction.....	3
Test Conditions	3
Evaluation Criteria	10
CRASH TEST 405160-1-1 (<i>NCHRP REPORT 350</i> TEST NO. 3-11).....	11
Test Vehicle	11
Soil and Weather Conditions	11
Impact Description.....	11
Damage to Test Article	14
Vehicle Damage.....	14
Occupant Risk Factors	14
SUMMARY AND CONCLUSIONS	21
ASSESSMENT OF TEST RESULTS	21
CONCLUSIONS.....	23
REFERENCES	25
APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS	27
ELECTRONIC INSTRUMENTATION AND DATA PROCESSING	27
ANTHROPOMORPHIC DUMMY INSTRUMENTATION.....	28
PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING	28
TEST VEHICLE PROPULSION AND GUIDANCE.....	28
APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION	29
APPENDIX C. SEQUENTIAL PHOTOGRAPHS	33
APPENDIX D. VEHICLE ANGULAR DISPLACEMENTS AND ACCELERATIONS	33

LIST OF FIGURES

	<u>Page</u>
Figure 1. Details of the Long-Span Guardrail – installation details.	4
Figure 2. Details of the Long-Span Guardrail – terminal details.	5
Figure 3. Details of the Long-Span Guardrail – post details.	6
Figure 4. Details of the Long-Span Guardrail – strut and blockout details.	7
Figure 5. Details of the Long-Span Guardrail – W-beam details.	8
Figure 6. Long-Span Guardrail prior to testing.	9
Figure 7. Vehicle/installation geometrics for test 405160-1-1.	12
Figure 8. Vehicle before test 405160-1-1.	13
Figure 9. Vehicle trajectory path after test 405160-1-1.	15
Figure 10. Installation after test 405160-1-1.	16
Figure 11. Vehicle after test 405160-1-1.	17
Figure 12. Interior of vehicle for test 405160-1-1.	18
Figure 13. Summary of results for <i>NCHRP Report 350</i> test 3-11 on the Long-Span Guardrail.	19
Figure 14. Vehicle properties for test 405160-1-1.	29
Figure 15. Sequential photographs for test 405160-1-1 (overhead and frontal views).	33
Figure 16. Vehicle angular displacements for test 405160-1-1.	35
Figure 17. Vehicle longitudinal accelerometer trace for test 405160-1-1 (accelerometer located at center of gravity).	36
Figure 18. Vehicle lateral accelerometer trace for test 405160-1-1 (accelerometer located at center of gravity).	37
Figure 19. Vehicle vertical accelerometer trace for test 405160-1-1 (accelerometer located at center of gravity).	38
Figure 20. Vehicle longitudinal accelerometer trace for test 405160-1-1 (accelerometer located over rear axle).	39
Figure 21. Vehicle lateral accelerometer trace for test 405160-1-1 (accelerometer located over rear axle).	40
Figure 22. Vehicle vertical accelerometer trace for test 405160-1-1 (accelerometer located over rear axle).	41

LIST OF TABLES

	<u>Page</u>
Table 1. Performance evaluation summary for <i>NCHRP Report 350</i> test 3-11 on the Long-Span Guardrail.....	24
Table 2. Exterior crush measurements for test 405160-1-1.....	30
Table 3. Occupant compartment measurements for test 405160-1-1.....	31

INTRODUCTION

PROBLEM

There are many instances where it is difficult to install guardrail posts at the normal 1.905 m (6.25 ft) spacing due to underground obstacles, such as culverts. Previously, designs for omitting 1 or 2 (3.8 to 5.7 m (12.5 to 18.75 ft) span) posts were crash tested in accordance with the *National Cooperative Highway Research Report (NCHRP) Report 230* criteria.⁽¹⁾ These designs required 7.6 to 11.4 m (25 ft to 37.5 ft) of nested rail to compensate for the increased post spacing. A design that omitted 3 posts (7.6 m (25 ft) span) was tested in accordance with *NCHRP Report 350*.^(2,3) This design was much more complex, requiring 30.5 m (100 ft) of nested rail, CRT posts at a reduced spacing on each side of the long span, and deeper blockouts. This *NCHRP Report 350* design may be over-designed for locations where only one or two posts need to be omitted.

BACKGROUND

In 1992, Mak, Bligh, Gripne and McDevitt reported on a study of long span guardrails with wood posts and offset blocks.⁽²⁾ They used a BARRIER VII program in a computer simulation study of several proposed designs of guardrails for spanning culverts. The “best” design identified in the computer study was a nested W-beam with post(s) omitted over the culvert. The nested W-beam guardrail with span lengths of 3.8 m (12.5 ft) and 5.7 m (18.75 ft) were subjected to full-scale tests using 2041 kg (4500 lb) automobiles in accordance with *NCHRP Report 230* and met the associated evaluation criteria. A 7.6 m (25 ft) length of nested W-beam was used in the 3.8 m (12.5 ft) long span design, and 11.4 m (37.5 ft) length of nested W-beam was used in the 5.7 m (18.75 ft) long span design.

In 1999, Polivka, et.al. reported on design and testing of a 7.6 m (25 ft) long span W-beam guardrail that made use of six CRT posts adjacent to the long span.^(4,5) Double depth offset blocks were used on the CRT posts and nested W-beam was used over a 30.5 m (100 ft) length. The design was tested with a 2000 kg (4400 lb) pickup in accordance with *NCHRP Report 350* and satisfactorily met the evaluation criteria.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this project was to develop a long-span guardrail design that meets *NCHRP Report 350* evaluation criteria and is less expensive to construct than the existing design.

The researchers reviewed design details of the long-span guardrails previously developed, especially the design presented by Mak⁽²⁾, to evaluate expected behavior of the guardrail when subjected to *NCHRP Report 350* tests. Design features that have been found to be important in terms of capacity of the guardrail to contain and redirect a vehicle are the

structural strength and geometrics of the guardrail. Lateral stiffness of the guardrail system is the primary design feature that determines maximum deflection of the guardrail during a collision and changes in lateral stiffness of the guardrail system along its length are the key features influencing pocketing of the vehicle.

The BARRIER VII computer program was used to evaluate expected performance of the proposed design in *NCHRP Report 350* tests. This program models a collision in two dimensions with a simple characterization of a vehicle and a detailed characterization of the guardrail. It was used to evaluate the expected deflections of the barrier and to predict any potential of the barrier to allow any unacceptable pocketing of the vehicle.

Reported herein are the details and results of the full-scale crash test performed on the long-span guardrail. Details of the installation and the test parameters are reported in the Technical Discussion, as well as the description of the test and the results. An assessment of the test results is given in the Summary and Conclusions.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of a 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 installation of the long-span guardrail is along a wide out-of-service runway/apron. The runway/apron consists of an unreinforced jointed concrete pavement in 3.8 m by 4.6 m blocks 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 consisted of 30.5 m (100 ft) of standard wood post W-beam guardrail (G4-2W) with 11.4 m (37.5 ft) long ET PLUS terminals installed on each end making the total installation length 45.7 m (150 ft). Two posts were omitted near mid length of the installation making a long span of 5.7 m (18 ft -9 inches). Nested W-beam (two layers) was installed over a length of 11.4 m (37 ft – 6 inches). The nested beam included the 5.7 m (18 ft – 9 inch) long span plus a 1.9 m (6 ft – 3 inch) span downstream and two 1.9 m (6 ft – 3 inch) spans upstream. Height to the top of the rail element was 686 mm (27 inches).

Test Conditions

According to *NCHRP Report 350*, two tests are recommended to evaluate longitudinal barriers to test level three (TL-3) and are as described below.

NCHRP Report 350 Test Designation 3-10: 820 kg vehicle impacting the length of need section at a speed of 100 km/h and an angle of 20 degrees.

NCHRP Report 350 Test Designation 3-11: 2000 kg pickup truck impacting the length of need section at a speed of 100 km/h and an angle of 25 degrees.

The small car test is performed for evaluating the general overall performance characteristics of the length of need section of a longitudinal barrier and occupant risk in particular. The pickup truck test is performed for the purpose of evaluating the ability of the barrier section to contain and redirect the vehicle. Occupant risk and vehicle stability are a

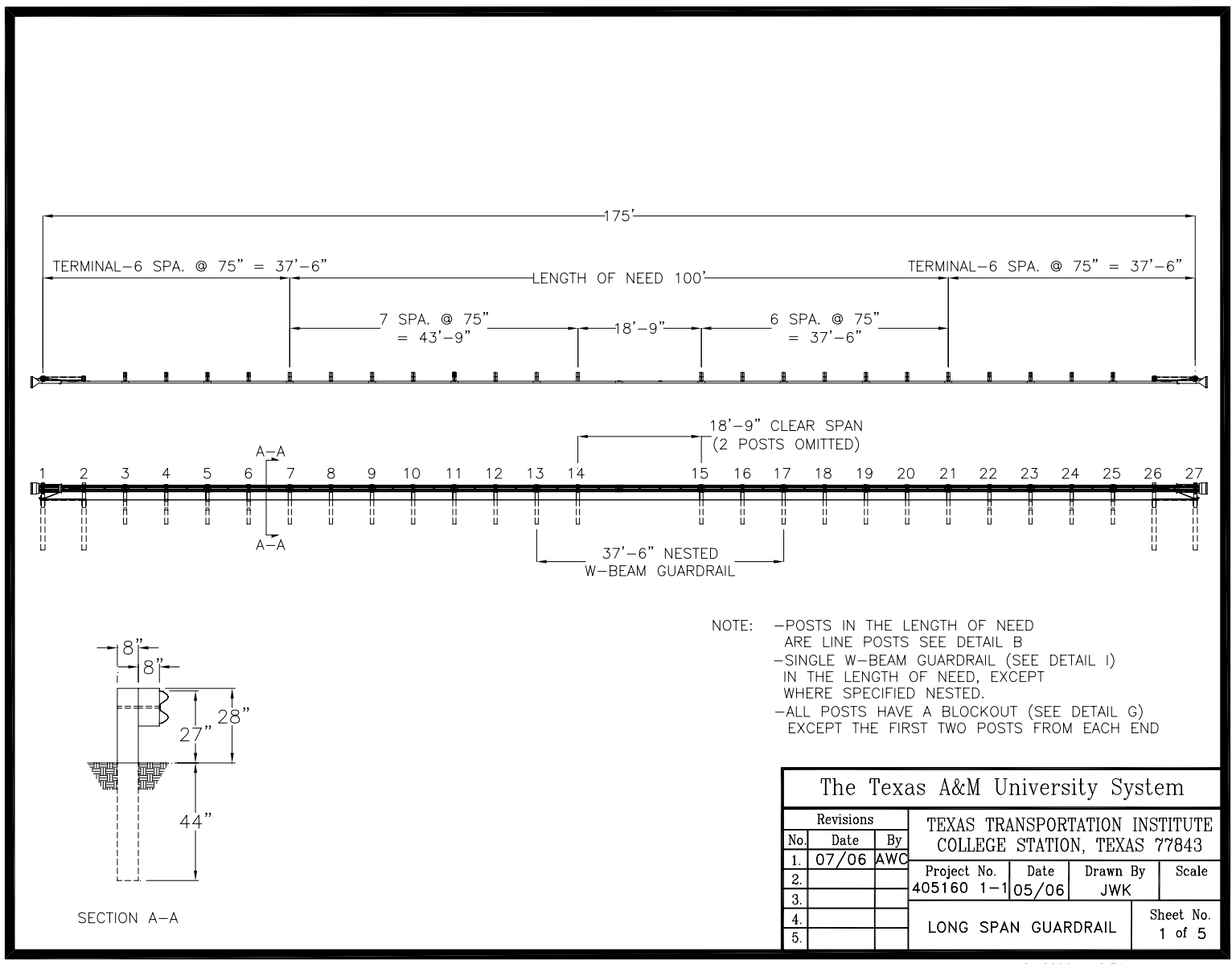
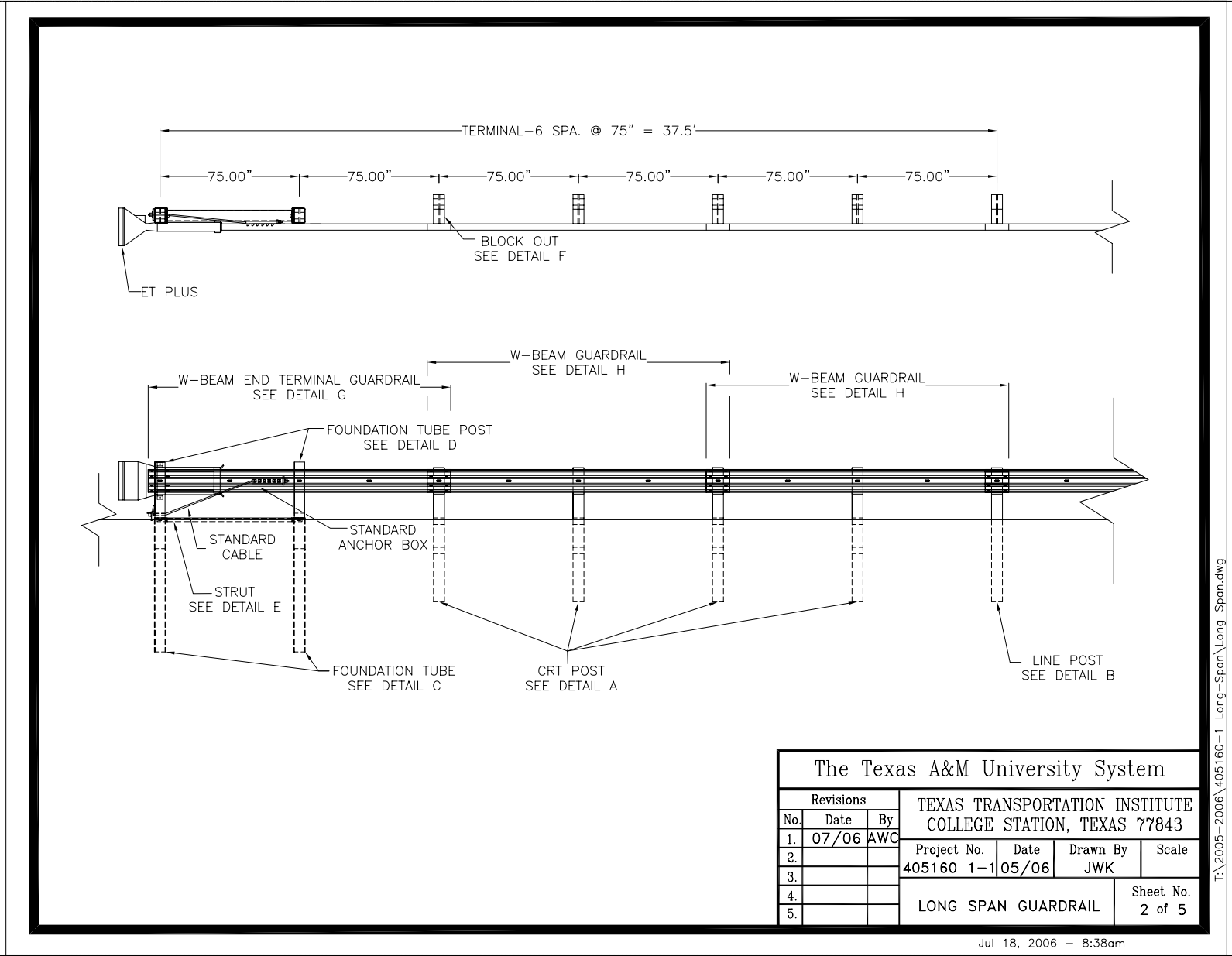


Figure 1. Details of the Long-Span Guardrail – installation details.

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4.			LONG SPAN GUARDRAIL	
5.			Sheet No. 2 of 5	

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Figure 2. Details of the Long-Span Guardrail – terminal details.

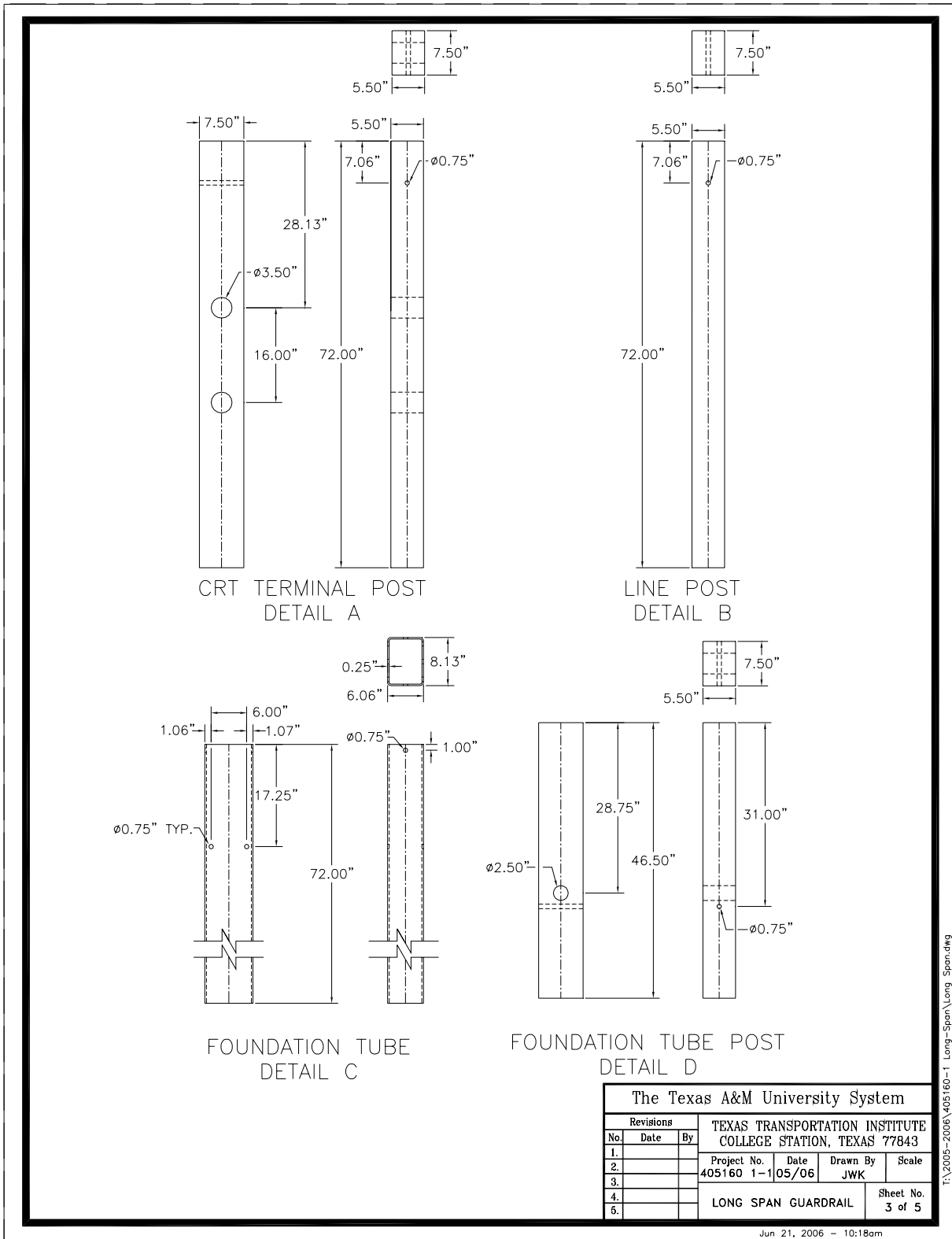
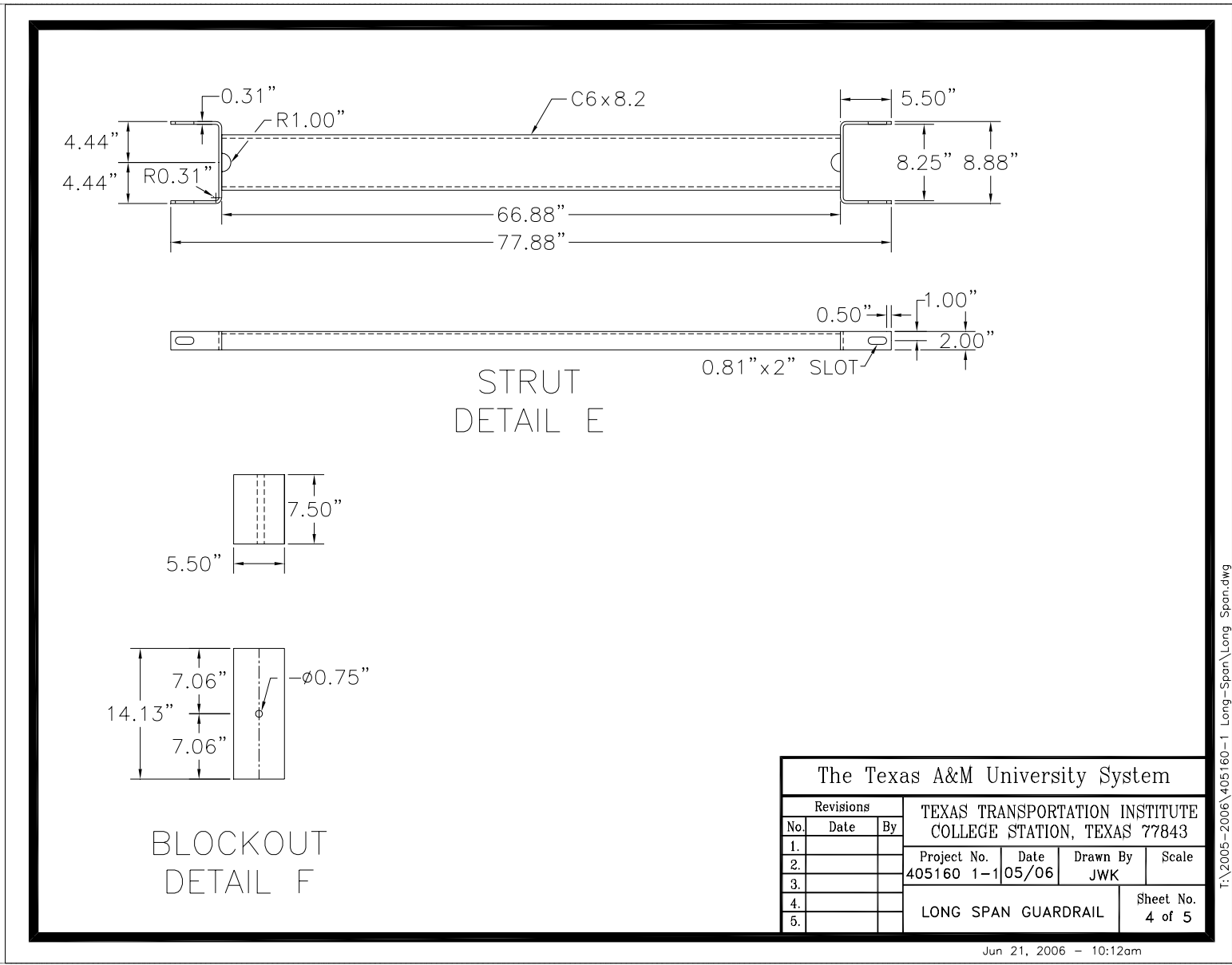


Figure 3. Details of the Long-Span Guardrail – post details.



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LONG SPAN GUARDRAIL			Sheet No. 4 of 5

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Figure 4. Details of the Long-Span Guardrail – strut and blockout details.

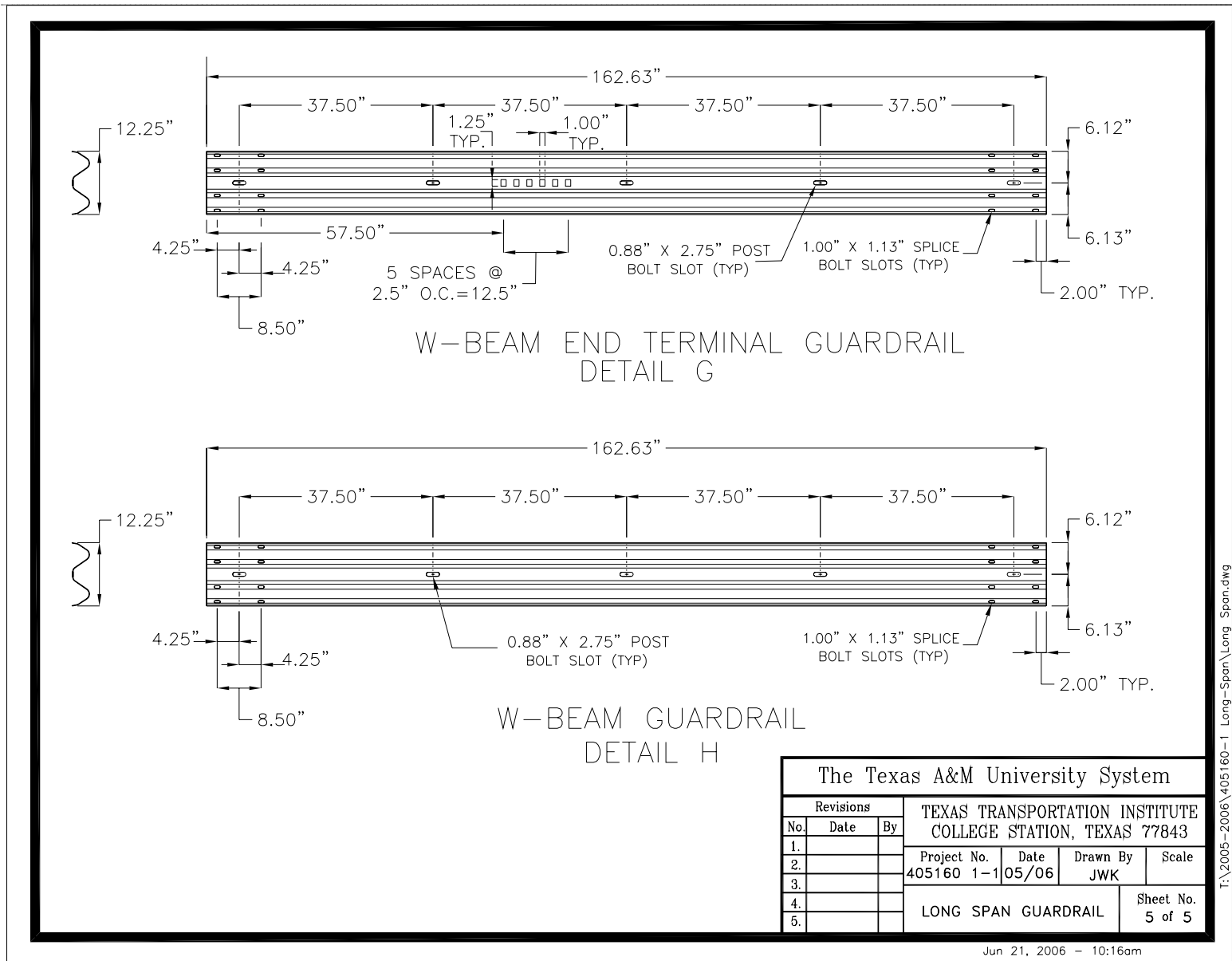


Figure 5. Details of the Long-Span Guardrail – W-beam details.



Figure 6. Long-Span Guardrail prior to testing.

concern in the evaluation of both these tests. Test 3-11 was performed in this study. The target impact location was 953 mm downstream of post 13, which was determined from BARRIER VII simulations to be the critical impact point for the long-space system..

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.

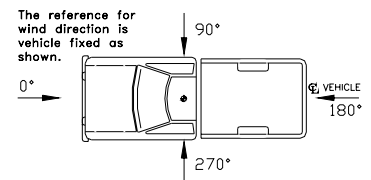
CRASH TEST 405160-1-1 (NCHRP REPORT 350 TEST NO. 3-11)

Test Vehicle

A 2000 Chevrolet C2500 pickup truck, shown in figures 7 and 8, was used for the crash test. Test inertia weight of the vehicle was 2143 kg, and its gross static weight was 2220 kg. The height to the lower edge of the vehicle front bumper was 415 mm, and the height to the upper edge of the front bumper was 635 mm. 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 25, 2006. No rainfall was 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: 20 km/h; wind direction: 335 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 29 °C.



Impact Description

The 2000 Chevrolet C2500 pickup truck, traveling at an impact speed of 100.5 km/h, impacted the long-span guardrail 953 mm downstream of post 13 at an impact angle of 24.8 degrees. At approximately 0.029 s, post 13 began to deflect towards the field side, and at 0.061 s, post 14 began to deflect towards field side. The vehicle began to redirect at 0.069 s. At 0.086 s, post 12 began to deflect towards field side, and at 0.115 s, post 15 began to deflect towards field side. The front of the vehicle reached post 14 at 0.179 s. At 0.193 s, post 16 began to deflect towards field side, and at 0.223 s, post 17 began to deflect towards field side. The front of the vehicle reached post 15 at 0.257 s. At 0.286 s, the vehicle began to travel parallel with the rail and was traveling at a speed of 72.3 km/h. The rail ruptured at post 13, where the section changed from nested to single layer, at 0.291 s. The front of the vehicle reached post 16 and 17 at 0.343 s and 0.443 s, respectively. The vehicle then began to roll clockwise and reached 90 degrees at 1.564 s after impact. After rolling onto its side, the vehicle then righted itself and landed on its wheels at 2.953 s. The vehicle came to rest upright 4.1 m toward the field side of the installation behind post 23. Sequential photographs of the test period are shown in appendix C, figure 15.



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



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

Damage to Test Article

Damage to the installation is shown in figures 9 and 10. The rail ruptured at post 13, where the section changed from nested to single layer. Posts 1 and 2 were disturbed, post 3 was pulled downstream 10 mm, and posts 4-5 were disturbed. Posts 6 and 7 were pulled upstream 10 mm, and posts 8 through 10 were disturbed and post 10 was partially split longitudinally. Posts 11 and 12 were pulled toward field side 100 mm and 540 mm, respectively. Post 13 through 19 fractured at ground level and posts 14 through 18 were separated from the rail element. Post 14 was resting 3.8 m on the traffic side forward of the traffic face of the rail. The rail element was also separated from posts 20 through 25, but remained attached to post 26. The blockouts were separated from posts 21, 23 and 24. Post 25 was split longitudinally. Prior to exiting the view of the overhead camera, the working width was 4.1 m. Prior to rupture of the rail element, the maximum deflection of the rail was 1.45 m.

Vehicle Damage

The vehicle sustained damage to the right side of the vehicle as shown in figure 11. The right upper and lower A-arm and right side frame rail were deformed. Also damaged were the front bumper, hood, grill, right front quarter panel, right door, right exterior bed, and right rear bumper. Maximum exterior crush to the vehicle was 540 mm in the frontal plane just to the right of centerline at bumper height. Maximum occupant compartment deformation was 16 mm in the right floor pan to instrument panel area. 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.

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 7.0 m/s at 0.224 s, maximum 0.010-s ridedown acceleration was -10.1 g's from 0.621 to 0.631 s, and the maximum 0.050-s average was -5.5 g's between 0.580 and 0.630 s. In the lateral direction, the occupant impact velocity was 3.0 m/s at 0.224 s, the highest 0.010-s occupant ridedown acceleration was -6.3 g's from 0.272 to 0.282 s, and the maximum 0.050-s average was -3.1 g's between 0.154 and 0.204 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 16 through 22.



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



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



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

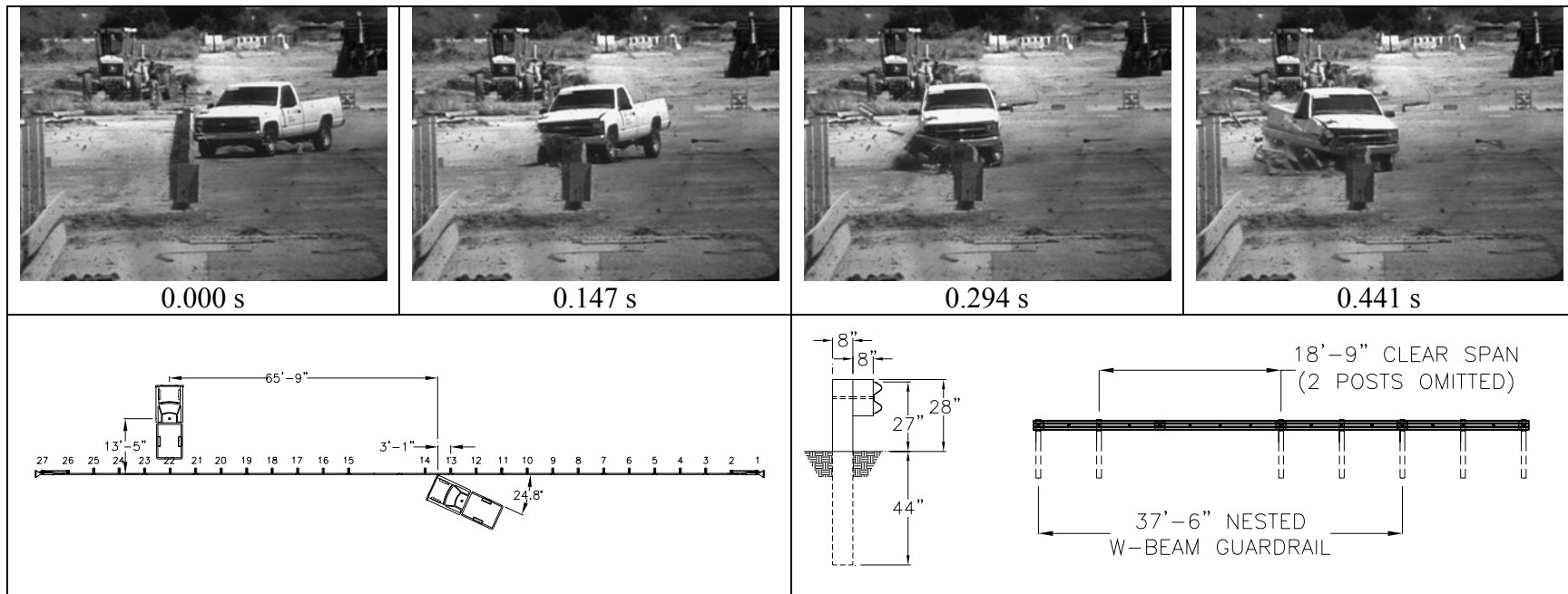


Before test



After test

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



General Information

Test Agency..... Texas Transportation Institute
 Test No. 405160-1-1
 Date 05-25-2006

Test Article

Type..... Guardrail
 Name Long-Span Guardrail
 Installation Length (m)..... 45.7
 Material or Key Elements Nested W-beam over 18 ft-9 inch long span plus a 6 ft-3 inch span downstream and two 6 ft-3 inch spans upstream
 Soil Type and Condition..... Standard Soil, Dry

Test Vehicle

Type..... Production
 Designation..... 2000P
 Model..... 2000 Chevrolet C2500 Pickup Truck
 Mass (kg)
 Curb..... 2153
 Test Inertial..... 2143
 Dummy 77
 Gross Static..... 2220

Impact Conditions

Speed (km/h) 100.5
 Angle (deg) 24.8

Exit Conditions

Speed (km/h) N/A
 Angle (deg) N/A

Occupant Risk Values

Impact Velocity (m/s)
 Longitudinal 7.0
 Lateral 3.0
 THIV (km/h) 24.2
 Ridedown Accelerations (g's)
 Longitudinal -10.1
 Lateral -6.3
 PHD (g's) 10.1
 ASI 0.54
 Max. 0.050-s Average (g's)
 Longitudinal -5.5
 Lateral -3.1
 Vertical 4.2

Test Article Deflections (m)

Dynamic Rail Ruptured
 Permanent..... Rail Ruptured
 Working Width..... 4.1

Vehicle Damage

Exterior
 VDS..... 01RFQ5
 CDC 01RFEW4
 Max. Exterior
 Vehicle Crush (mm) 540
 Interior
 OCDI RF0002000
 Max. Occupant Compartment
 Deformation (mm) 16

Post-Impact Behavior

(during 1.0 sec after impact)
 Max. Yaw Angle (deg)..... -250
 Max. Pitch Angle (deg)..... -9
 Max. Roll Angle (deg) 100

Figure 13. Summary of results for *NCHRP Report 350* test 3-11 on the Long-Span Guardrail.

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 Long-Span Guardrail did not contain or redirect the vehicle. The vehicle penetrated the rail element with a maximum dynamic deflection of 1.45 m before the rail ruptured. (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: Some of the posts fractured and post 14 was resting 3.8 m on the traffic side of the rail. These debris did not penetrate nor show potential for penetrating the occupant compartment. Maximum occupant compartment deformation was 16 mm in the right floor pan to instrument panel area. (PASS)

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

Results: The vehicle rolled 90 degrees and then 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 did not intrude into adjacent traffic lanes as it came to rest on the field side of the installation. (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.*

Result: Longitudinal occupant impact velocity was 7.0 m/s, and the longitudinal ridedown acceleration was -10.1 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: The vehicle ruptured the rail and exited behind the installation. (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: ⁽⁶⁾

Passenger Compartment Intrusion

1. *Windshield Intrusion*

- | | |
|---|---|
| a. <i>No windshield contact</i> | e. <i>Complete intrusion into passenger compartment</i> |
| b. <i>Windshield contact, no damage</i> | f. <i>Partial intrusion into passenger compartment</i> |
| c. <i>Windshield contact, no intrusion</i> | |
| d. <i>Device embedded in windshield, no significant intrusion</i> | |

2. *Body Panel Intrusion*

yes or no

Loss of Vehicle Control

- | | |
|---|--|
| 1. <i>Physical loss of control</i> | 3. <i>Perceived threat to other vehicles</i> |
| 2. <i>Loss of windshield visibility</i> | 4. <i>Debris on pavement</i> |

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*

Some of the posts fractured and post 14 was resting 3.8 m forward of the traffic face of the rail.

Vehicle and Device Condition

1. *Vehicle Damage*

- | | |
|---|--|
| a. <i>None</i> | d. <i>Major dents to grill and body panels</i> |
| b. <i>Minor scrapes, scratches or dents</i> | e. <u><i>Major structural damage</i></u> |
| c. <i>Significant cosmetic dents</i> | |

2. *Windshield Damage*

- | | |
|--|--|
| a. <u><i>None</i></u> | e. <i>Shattered, remained intact but partially dislodged</i> |
| b. <i>Minor chip or crack</i> | f. <i>Large portion removed</i> |
| c. <i>Broken, no interference with visibility</i> | g. <i>Completely removed</i> |
| d. <i>Broken or shattered, visibility restricted but remained intact</i> | |

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 rail element ruptured and allowed the vehicle to penetrate the rail system. The vehicle subsequently rolled onto its side. Therefore, the rail failed evaluation criteria for *NCHRP Report 350* test 3-11, as shown in table 1. The abrupt change in stiffness of the rail element where it changes from two layer of W-beam (nested) to a single layer may have contributed to rupture of the single layer rail element.

Table 1. Performance evaluation summary for *NCHRP Report 350* test 3-11 on the Long-Span Guardrail.

Test Agency: Texas Transportation Institute

Test No.: 405160-1-1

Test Date: 05-25-2006

<i>NCHRP Report 350</i> Evaluation Criteria	Test Results	Assessment
<p><u>Structural Adequacy</u></p> <p>A. <i>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</i></p>	<p>The Long-Span Guardrail did not contain or redirect the vehicle. The vehicle penetrated the rail element with a maximum dynamic deflection of 1.45 m before the rail ruptured.</p>	<p>Fail</p>
<p><u>Occupant Risk</u></p> <p>D. <i>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.</i></p>	<p>Some of the posts fractured and post 14 was resting 3.8 m forward of the traffic face of the rail. These debris did not penetrate nor show potential for penetrating the occupant compartment. Maximum occupant compartment deformation was 16 mm in the right floor pan to instrument panel area.</p>	<p>Pass</p>
<p>F. <i>The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</i></p>	<p>The vehicle rolled 90 degrees and then came to rest upright.</p>	<p>Fail</p>
<p><u>Vehicle Trajectory</u></p> <p>K. <i>After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</i></p>	<p>The vehicle did not intrude into adjacent traffic lanes as it came to rest on the field side of the installation.</p>	<p>Pass*</p>
<p>L. <i>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.</i></p>	<p>Longitudinal occupant impact velocity was 7.0 m/s, and the longitudinal ridedown acceleration was -10.1 g.</p>	<p>Pas</p>
<p>M. <i>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.</i></p>	<p>The vehicle ruptured the rail and exited behind the installation.</p>	<p>N/A*</p>

*Criterion K and M are preferable, not required.

REFERENCES

1. J.D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report 230, Transportation Research Board, National Research Council, Washington, D.C., 1981.
2. K.K. Mak, R.P. Bligh, D.J. Gripne and C.F. McDevitt, “Long-Span Nested W-Beam Guardrails over Low-Fill Culverts,” *Transportation Research Record No. 1367*, Transportation Research Board, National Research Council, Washington, D.C., 1992.
3. 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.
4. K.A. Polivka, B.W. Bielenberg, D.L. Sicking, R.K. Faller, and J.R. Rohde, “Development of a 7.62-m Long Span Guardrail System,” MwRSF Research Report No. TRP-03-72-99, Midwest State’s Regional Pooled Fund Program, Lincoln, NB, April 1999.
5. K.A. Polivka, B.W. Bielenberg, D.L. Sicking, R.K. Faller, and J.R. Rohde, “Development of a 7.62-m Long Span Guardrail System – Phase II,” MwRSF Research Report No. TRP-03-88-99, Midwest State’s Regional Pooled Fund Program, Lincoln, NB, August 1999.
6. 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/compartiment impact velocities, time of occupant/compartiment 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 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: 05-25-2006 Test No.: 405160-1-1 VIN No.: 1GCGC24R2YR192376

Year: 2000 Make: Chevrolet Model: C2500

Tire Inflation Pressure: _____ Odometer: 167313 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 liter

Transmission Type:

Auto

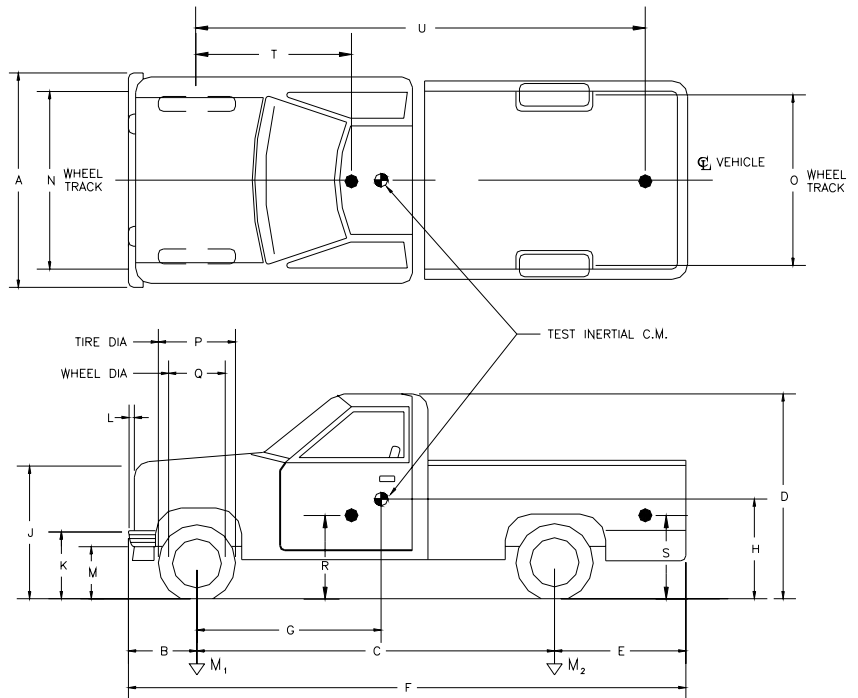
Manual

Optional Equipment: _____

Dummy Data: Type: 50th percentile

Mass: 77 kg

Seat Position: Passenger



Geometry (mm)

A	<u>1880</u>	E	<u>1310</u>	J	<u>1038</u>	N	<u>1590</u>	R	<u>750</u>
B	<u>810</u>	F	<u>5470</u>	K	<u>635</u>	O	<u>1610</u>	S	<u>900</u>
C	<u>3350</u>	G	<u>1447.55</u>	L	<u>70</u>	P	<u>725</u>	T	<u>1460</u>
D	<u>1820</u>	H	_____	M	<u>415</u>	Q	<u>440</u>	U	<u>3360</u>

Mass (kg)	Curb	Test Inertial	Gross Static
M ₁	<u>1224</u>	<u>1217</u>	<u>1260</u>
M ₂	<u>929</u>	<u>926</u>	<u>960</u>
M _{Total}	<u>2153</u>	<u>2143</u>	<u>2220</u>

Mass Distribution (kg): LF: 605 RF: 612 LR: 462 RR: 464

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

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

VEHICLE CRUSH MEASUREMENT SHEET¹

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 $\frac{X1 + X2}{2} = \underline{\hspace{2cm}}$

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		Field L**	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	±D
		Width** (CDC)	Max*** Crush								
1	Front plane – bumper ht	900	540	1600	-150	-70	200	540	350	450	0
2	Side plane – bumper ht	900	330	1040	0	65	N/A	N/A	300	330	1550

¹Table 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).

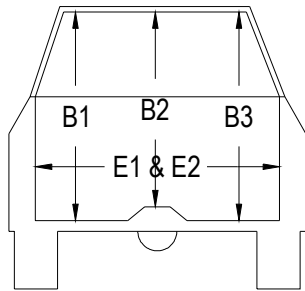
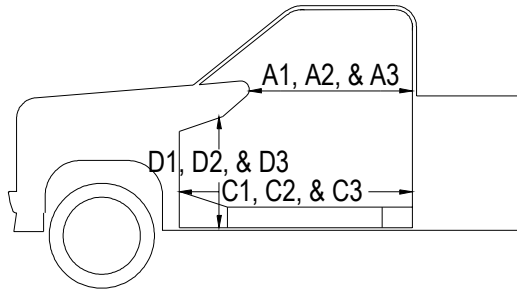
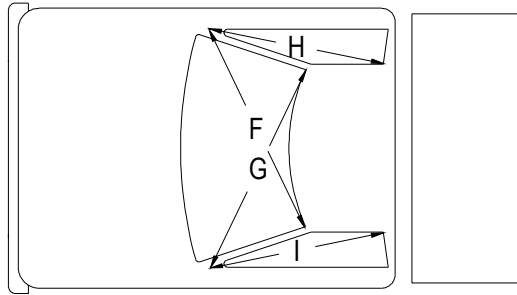
***Measure and document on the vehicle diagram the location of the maximum crush.

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

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

Truck

Occupant Compartment Deformation



	BEFORE (mm)	AFTER (mm)
A1	868	868
A2	936	936
A3	932	932
B1	1072	1072
B2	947	932
B3	1068	1061
C1	1370	1370
C2	----	----
C3	1366	1366
D1	326	326
D2	158	147
D3	307	291
E1	1585	1590
E2	1587	1598
F	1470	1470
G	1470	1470
H	1060	1060
I	1060	1060
J*	1525	1514

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

APPENDIX C. SEQUENTIAL PHOTOGRAPHS



0.000 s



0.074 s



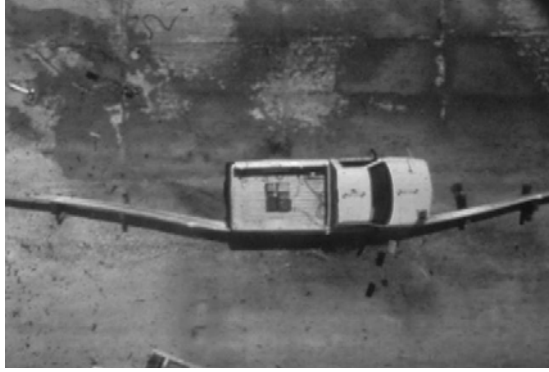
0.147 s



0.220 s



Figure 15. Sequential photographs for test 405160-1-1 (overhead and frontal views).



0.294 s



0.367 s



0.441 s



0.514 s



Figure 15. Sequential photographs for test 405160-1-1 (overhead and frontal views) (continued).

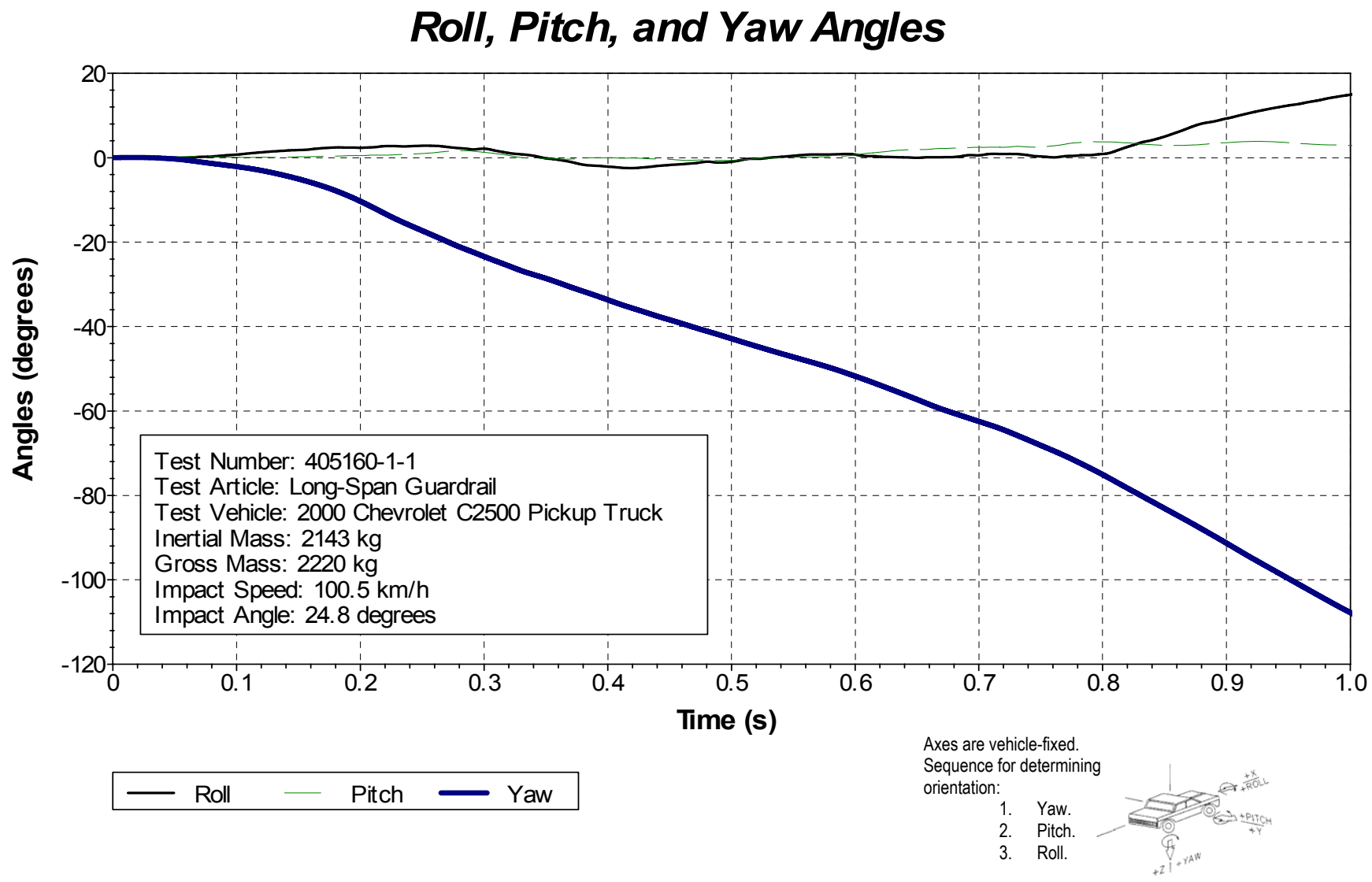


Figure 16. Vehicle angular displacements for test 405160-1-1.

X Acceleration at CG

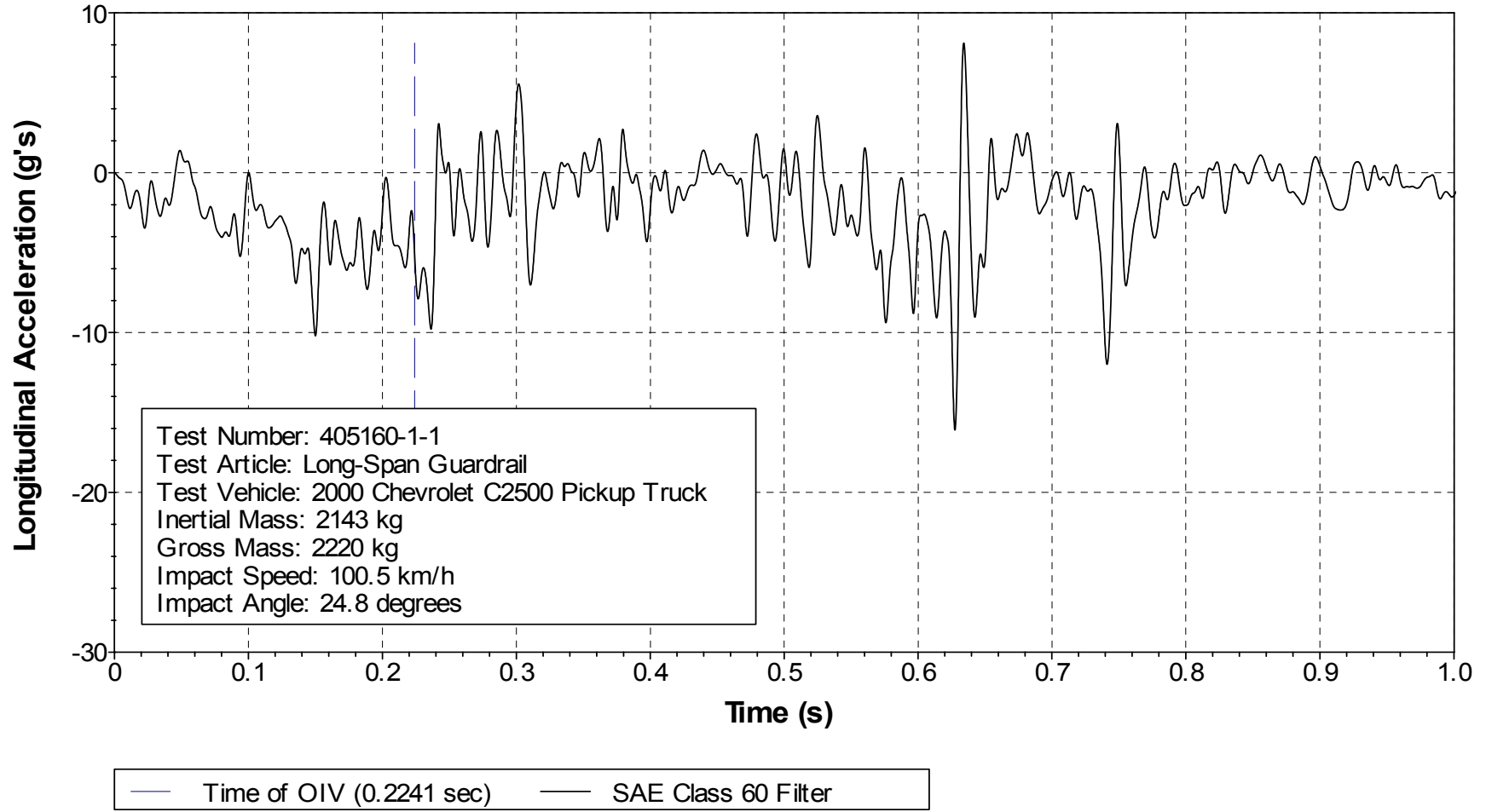


Figure 17. Vehicle longitudinal accelerometer trace for test 405160-1-1 (accelerometer located at center of gravity).

Y Acceleration at CG

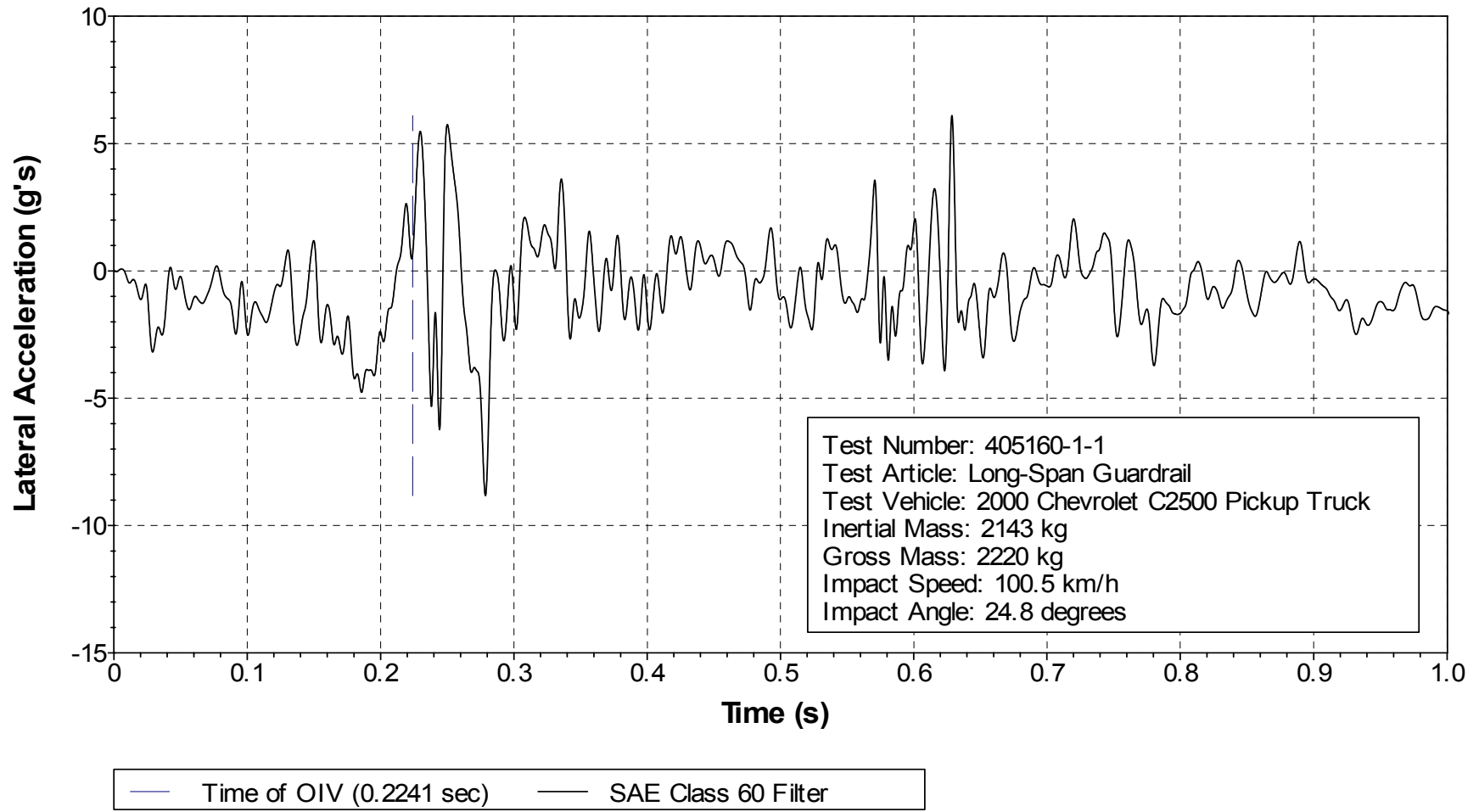


Figure 18. Vehicle lateral accelerometer trace for test 405160-1-1 (accelerometer located at center of gravity).

Z Acceleration at CG

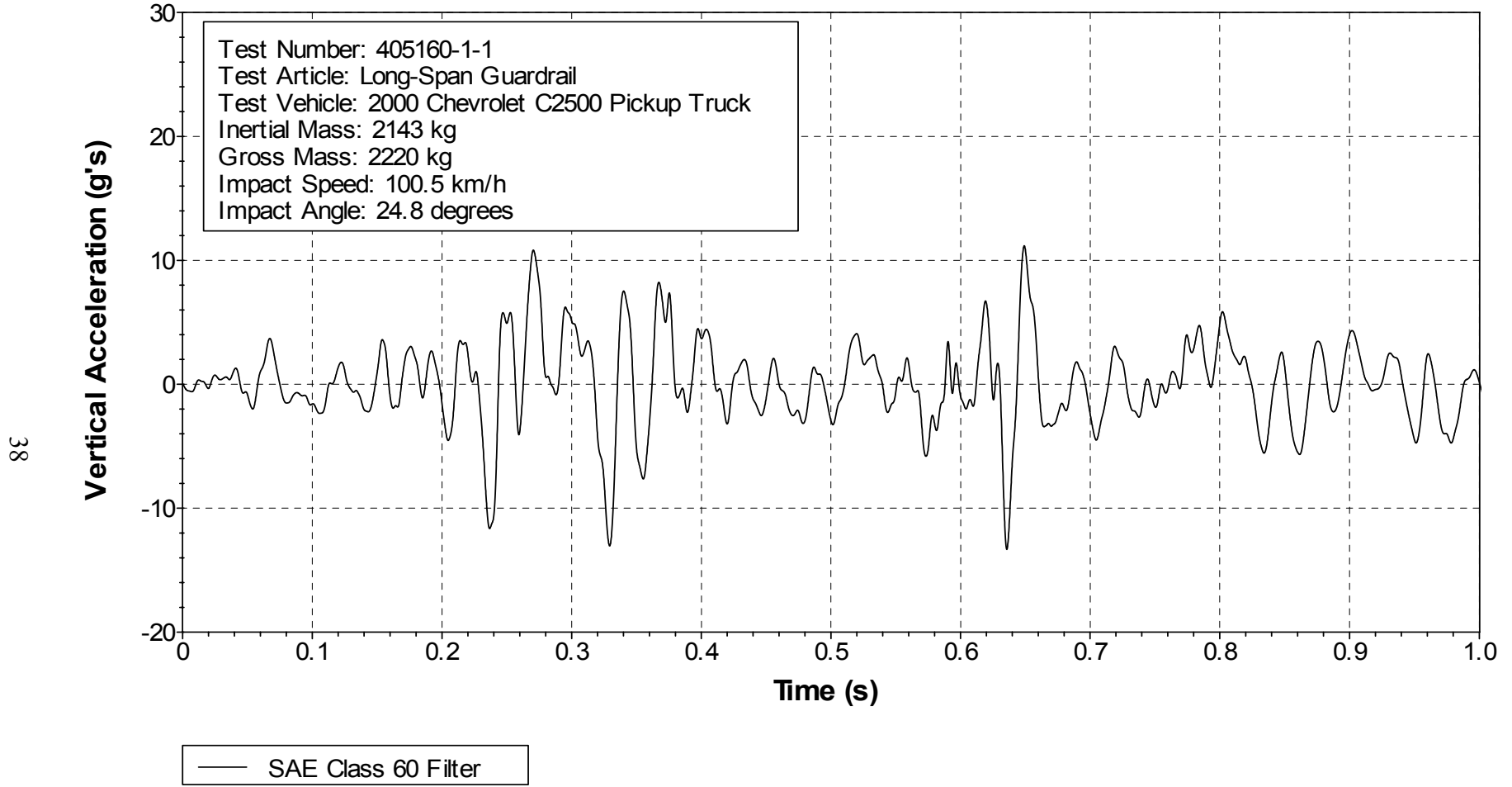


Figure 19. Vehicle vertical accelerometer trace for test 405160-1-1 (accelerometer located at center of gravity).

X Acceleration over Rear Axle

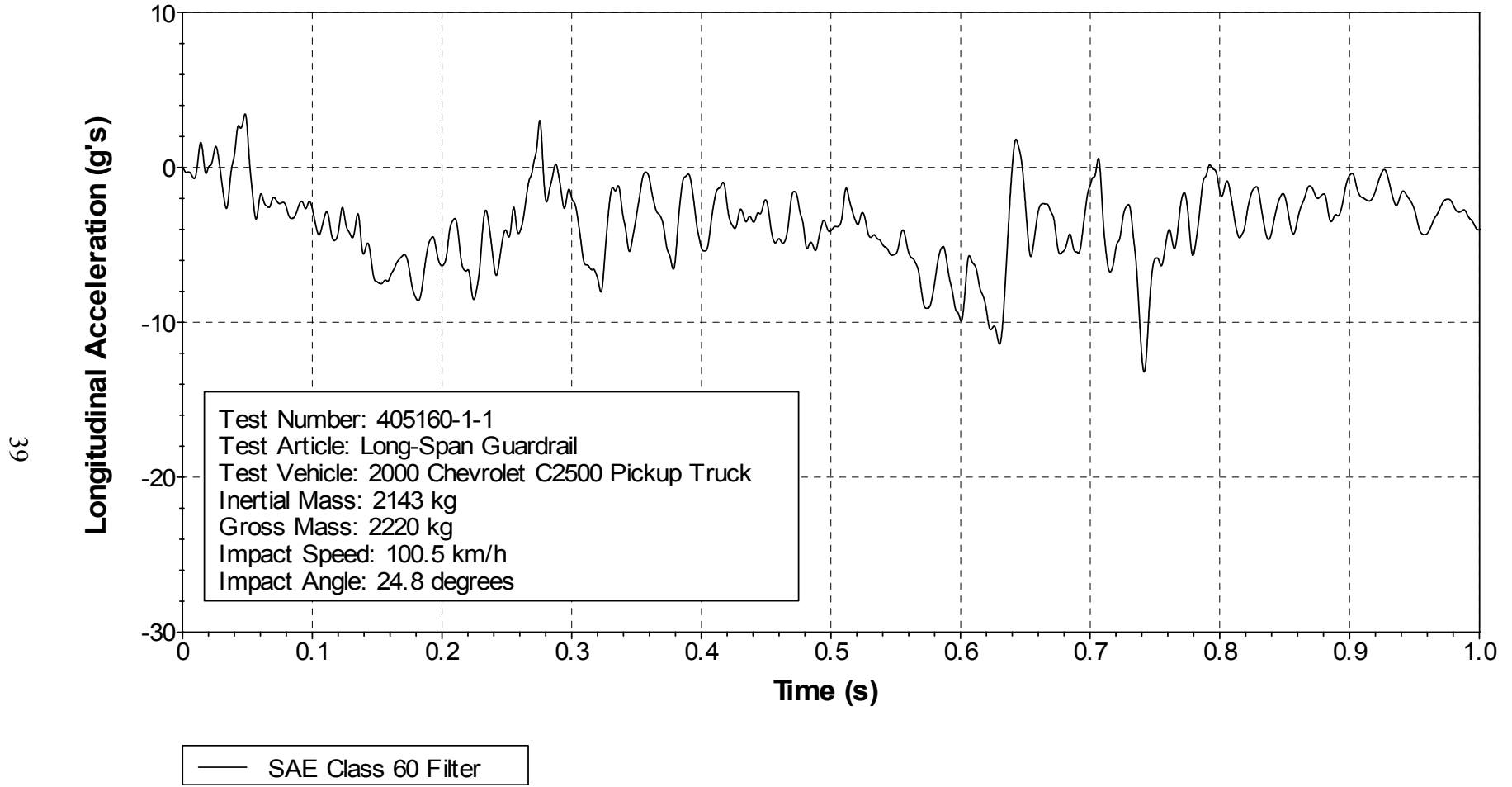


Figure 20. Vehicle longitudinal accelerometer trace for test 405160-1-1 (accelerometer located over rear axle).

Y Acceleration over Rear Axle

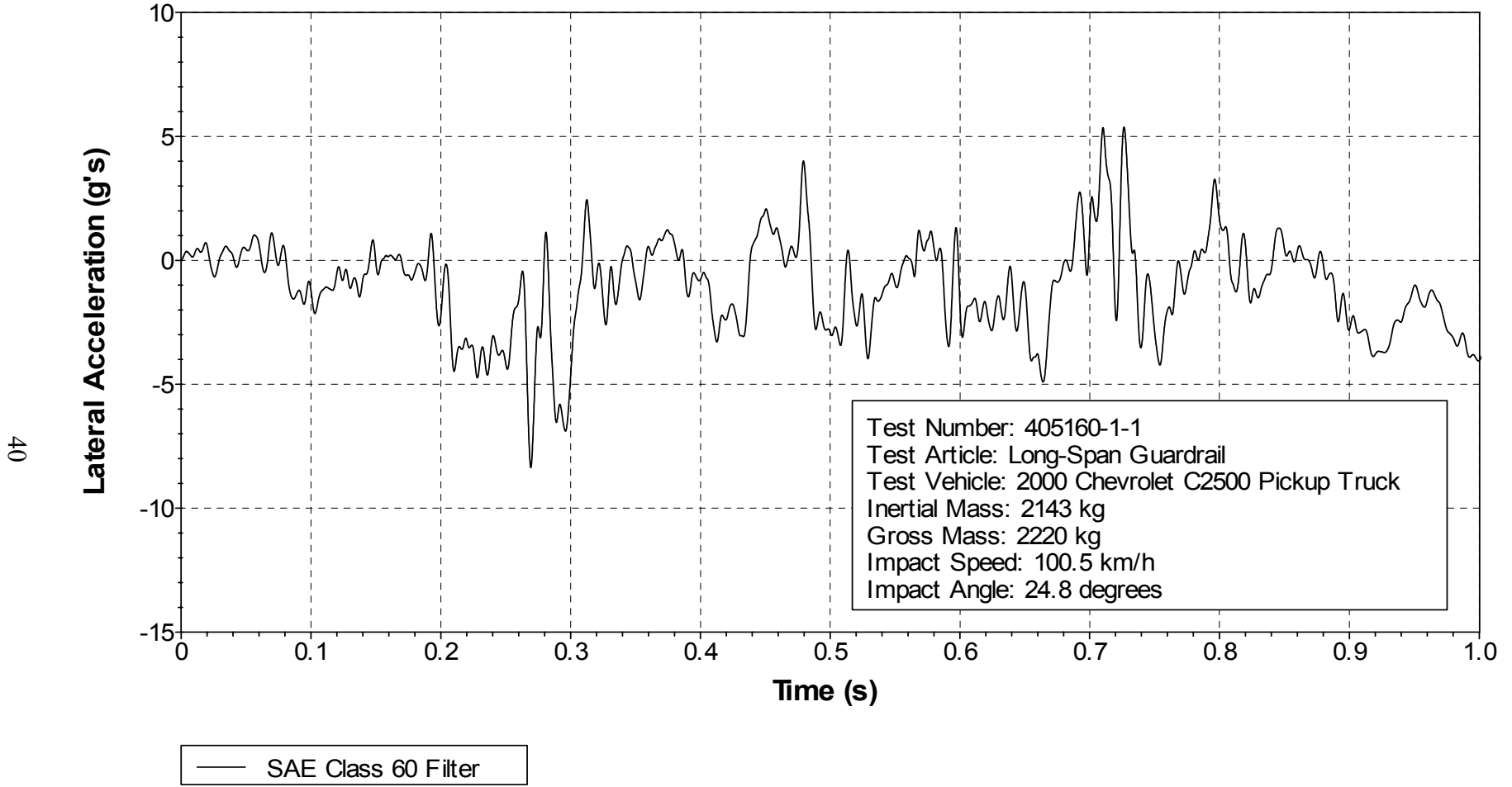


Figure 21. Vehicle lateral accelerometer trace for test 405160-1-1 (accelerometer located over rear axle).

Z Acceleration over Rear Axle

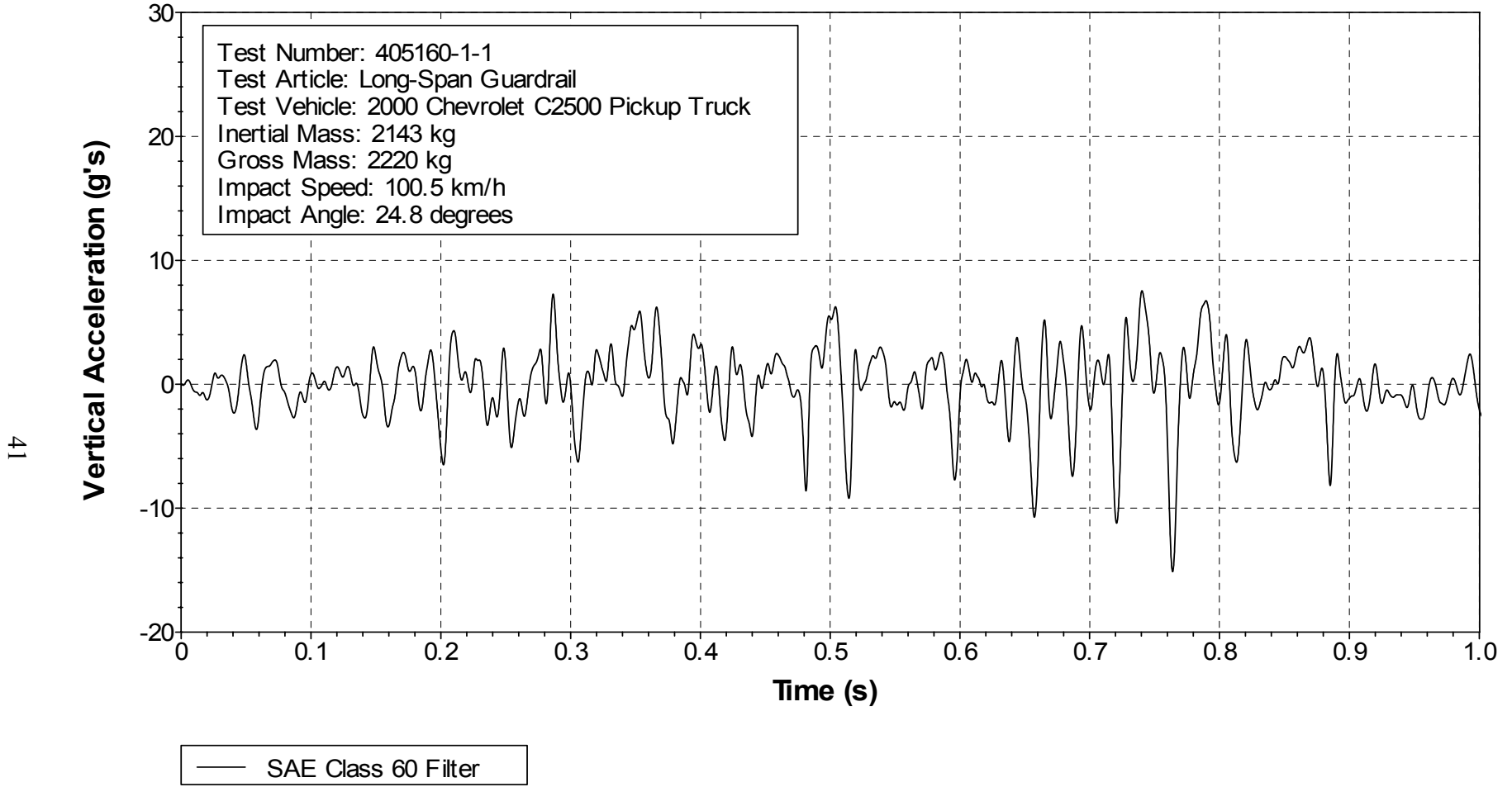


Figure 22. Vehicle vertical accelerometer trace for test 405160-1-1 (accelerometer located over rear axle).