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16. Abstract <p>The objectives of this portion of the project were to: 1) determine if any or all of the three subject variants of the 32-inch (813 mm) Jersey safety shaped bridge railing comply with the requirements of the <i>AASHTO LRFD Bridge Design Specifications</i> and National Cooperative Highway Research Program (<i>NCHRP Report 350</i> Test Level 4 (TL-4), and 2) provide recommended retrofit schemes, if deemed technically and economically feasible, to bring into compliance the railings that do not comply. Full or partial replacement schemes may also be recommended as appropriate.</p> <p>The most direct approach for accomplishing the objectives of this task was to perform a full-scale crash test of the most critical design. If that railing performed satisfactorily, the railing would be acceptable by <i>AASHTO LRFD Specifications</i>. The strength test was selected, <i>NCHRP Report 350</i> test 4-12, a single-unit van-type truck weighing 17,621 lb (8000 kg). The TL-4 vehicle is a single-unit box-van truck impacting the railing at 15 degrees and 49.7 mi/h (80 km/h). While containment is required, overturning of the vehicle is an acceptable test outcome. However, Test Level 3 (TL-3) is a 4405-lb (2000 kg) pickup impacting the railing at 25 degrees and 62.2 mi/h (100 km/h). This test requires both containment and stability, and non-overturning. Since some breakage of the parapet is possible, potential for vehicle snagging is likely. Vehicle snagging can contribute to vehicle instabilities in the redirection sequence and potential rollover. Therefore, researchers chose both TL-4 and TL-3 tests.</p> <p>According to the results of this project, no field retrofits or replacements of the Florida Jersey safety shaped bridge rails, depicted in the Florida DOT Index 799, are warranted since the most critical 32-inch (813 mm) Jersey safety shaped bridge railing complied with the requirements of the <i>AASHTO LRFD Bridge Design Specifications</i> and <i>NCHRP Report 350</i> Test Levels 3 and 4.</p>					
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**TESTING AND EVALUATION OF THE
FLORIDA JERSEY SAFETY SHAPED BRIDGE RAIL**

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CHAPTER 1. INTRODUCTION

PROBLEM

The Florida Department of Transportation (FDOT) uses the Jersey safety shaped barrier extensively on highways today. A number of the designs from previous years have minimal reinforcement and when the current design procedure is used to evaluate the respective designs, the analysis indicates marginal performance may be anticipated when impacted by an errant vehicle. Therefore, FDOT elected to perform a full-scale crash test of the most critical design deployed in the field.

BACKGROUND

The American Association of State Highway and Transportation Official's (*AASHTO Load Resistance Factor Design (LRFD) Bridge Specifications* Section 13 sets forth test levels and the required test conditions for demonstrating a bridge rail meets a certain test level (1). The Appendix to Section 13 gives engineering guidelines for designing bridge rails that will perform satisfactorily in full-scale crash tests. The Appendix to Section 13 is not mandatory. Bridge rails may be designed by other methods and would be considered acceptable if the rail performed satisfactorily in crash tests.

Ultimately, a bridge rail should contain and redirect errant vehicles with minimal damage to the bridge structure. Most states use a number of different types of concrete safety-shaped bridge rails. Over the years, a number of different reinforcement schemes have been used and most have withstood the rigors of the highway environment. One end of the spectrum for steel reinforcement in concrete barriers is the Ontario "Tall Wall" (2). The Ontario "Tall Wall" is a safety-shaped median barrier that was successfully crash tested with a 80,000-lb (36,000 kg) tractor/trailer, and no steel reinforcement was used in the system. The T501 is a common safety-shaped bridge rail used extensively in Texas. The T501 uses a moderate amount of steel reinforcement. Other barriers use extensive reinforcement. Obviously, reinforcement schemes may vary significantly and still achieve the objective to contain and redirect errant vehicles.

As experience is gained with bridge rails, designs change. The geometry, such as height, shape, and openness, may change due to vehicle mix, vehicle design changes, or public opinion. However, a move to a new design does not necessarily negate the usefulness of older systems, nor does an upgrade in design automatically indicate the older system will not perform acceptably when impacted under new design conditions. The safety performance of bridge rails is ultimately evaluated by a performance-based test, i.e., a full-scale crash test.

OBJECTIVES/SCOPE OF RESEARCH

The objectives of this portion of the study were to:

1. Determine if any or all of the three subject variants of the 32-inch (813 mm) Jersey safety shaped bridge railing comply with the requirements of the *AASHTO LRFD Bridge Design Specifications* and National Cooperative Highway Research Program (*NCHRP*) Report 350 Test Level 4 (3).
2. Provide recommended retrofit schemes, if deemed technically and economically feasible, to bring into compliance the railings that do not comply. Full or partial replacement schemes may also be recommended as appropriate.
3. Prepare a comprehensive report of research findings and recommendations that is suitable for submittal to the Federal Highway Administration (FHWA) by FDOT as part of a request for acceptance package.

The most direct approach for accomplishing the objectives of this task is to perform a full-scale crash test of the most critical railing design. If that railing performs satisfactorily, the railing would be acceptable by *AASHTO LRFD Specifications*. The test that is needed is the strength test for the test level of interest; in this instance, *NCHRP Report 350* test 4-12, a single-unit van-type truck weighing 17,621 lb (8000 kg).

The researchers understand the reinforcement used in each of the three variants is uniform in size and spacing throughout the length of the railing installation. That is, additional reinforcement is not used near the end of the railing to strengthen the end. This would make the railing less capable of withstanding an impact near the end of the railing. However, the researchers recommend that the first test be performed with the impact point along the mid-length of the railing. This test will prove or disprove the basic railing is adequate for *NCHRP Report 350* Test Level 4 (TL-4). In the event the basic railing is adequate, the second test will be performed with the impact point near the end in order to determine the adequacy of the end segment of the railing.

The TL-4 vehicle is a single-unit box-van truck impacting the railing at 15 degrees and 49.7 mi/h (80 km/h). While containment is required, overturning of the vehicle 90 degrees is an acceptable test outcome. However, Test Level 3 (TL-3) is a 4405-lb (2000 kg) pickup impacting the railing at 25 degrees and 62.2 mi/h (100 km/h). This test requires both containment and stability, and non-overturning. Since some breakage of the parapet is possible, potential for vehicle snagging is likely. Vehicle snagging can contribute to vehicle instabilities in the redirection sequence and potential rollover. Therefore, both TL-4 and TL-3 tests should be considered.

CHAPTER 2. STUDY APPROACH

TEST FACILITY

The test facilities at the Texas Transportation Institute's Proving Ground consist of a 2000-acre (809 hectare) complex of research and training facilities situated 10 mi (16 km) northwest of the main campus of Texas A&M University. The site, formerly an Air Force Base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placing of the Florida Jersey safety shaped bridge rail is along a wide out-of-service apron/runway. The apron/runway consists of an unreinforced jointed-concrete pavement in 12.5 ft by 15 ft (3.8 m by 4.6 m) blocks nominally 8 to 12 inches (203 to 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 Florida Jersey safety shaped barrier selected for testing is depicted in FDOT Sheet Index No. I-799 and more specifically Index Nos. 13857 and 14101 of that sheet. It is a 32-inch (813 mm) tall, 6-inch (152 mm) top, and 15-inch (382 mm) base Jersey safety shaped concrete barrier integrally cast with a 7-inch (178 mm) thick reinforced concrete simulated bridge deck. Longitudinal reinforcement in the bridge parapet is six (6) #4 (#13) bars, three (3) on each face. "U" shaped #4 (#13) stirrups spaced 8 inches (203 mm) on center are contained entirely in the parapet and extend into the slender portion of the parapet. "A" shaped #4 (#13) stirrups spaced 8 inches (203 mm) on center hook and align with the "U" bars and parallel the lower sloped face of the parapet and extend into the lower mat of the bridge deck. "L" shaped #4 (#13) stirrups at 8 inches (203 mm) on center are placed in the back face of the parapet and extend into the lower mat of the simulated bridge deck. The 7-inch (178 mm) thick bridge deck is laterally reinforced with #5 (#16) bars at 6 inches on center in the top mat and #5 (#16) bars at 12 inches (305 mm) on center in the bottom mat. There were also six (6) #4 (#13) longitudinal bars in the deck. Concrete strengths were 3616 psi (25 MPa) in the parapet and 3931 psi (27 MPa) in the deck. All exposed corners received 3/4 inch (19 mm) chamfer. Additionally, 2-inch (51 mm) expansion joints were cast in the parapets for testing purposes. The deck was continuous. There was no extra reinforcement at expansion joints per the state drawings. Figures 1 and 2 provide more details on the parapet and deck, and Figure 3 presents photographs of the test installation.

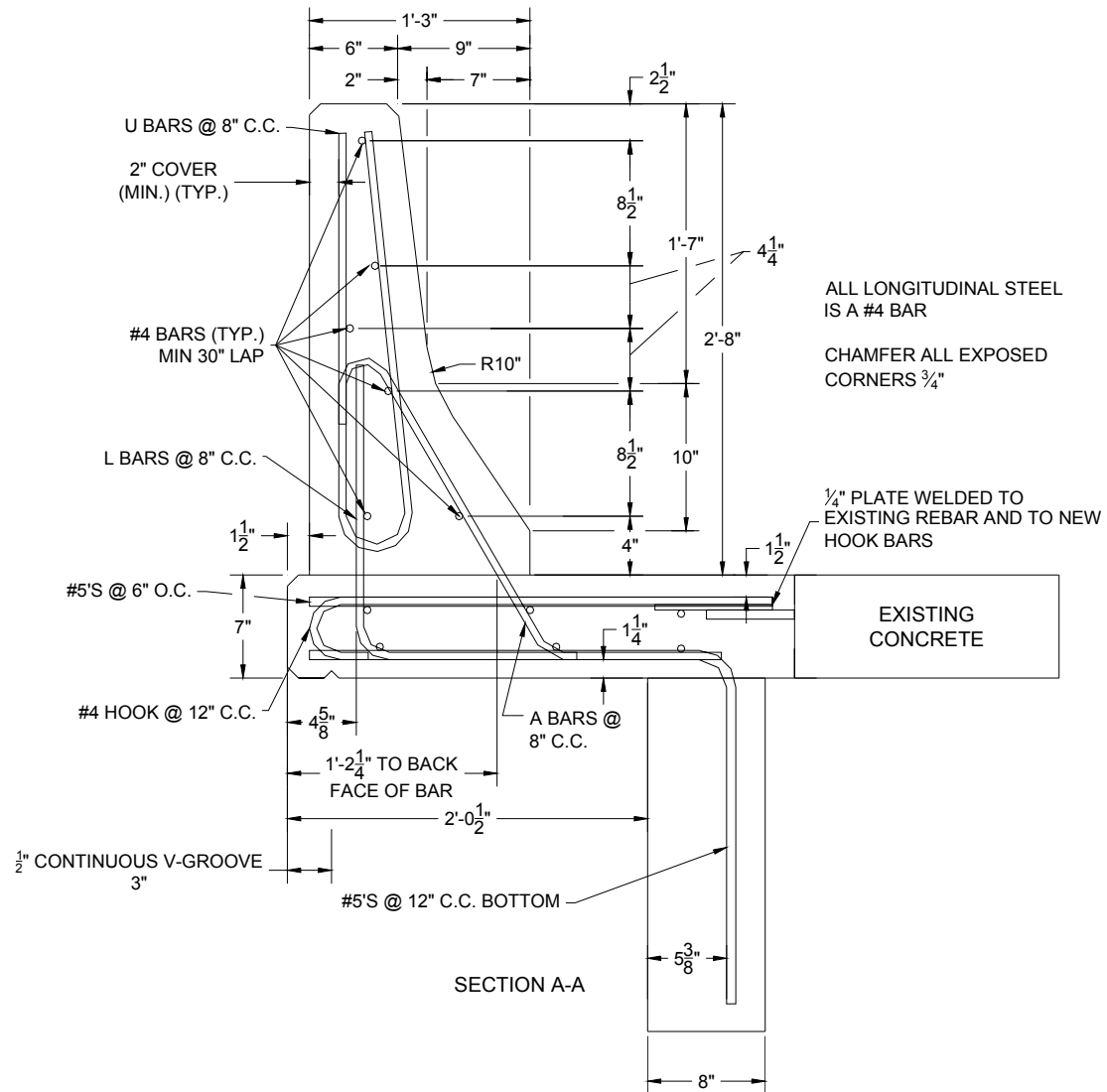
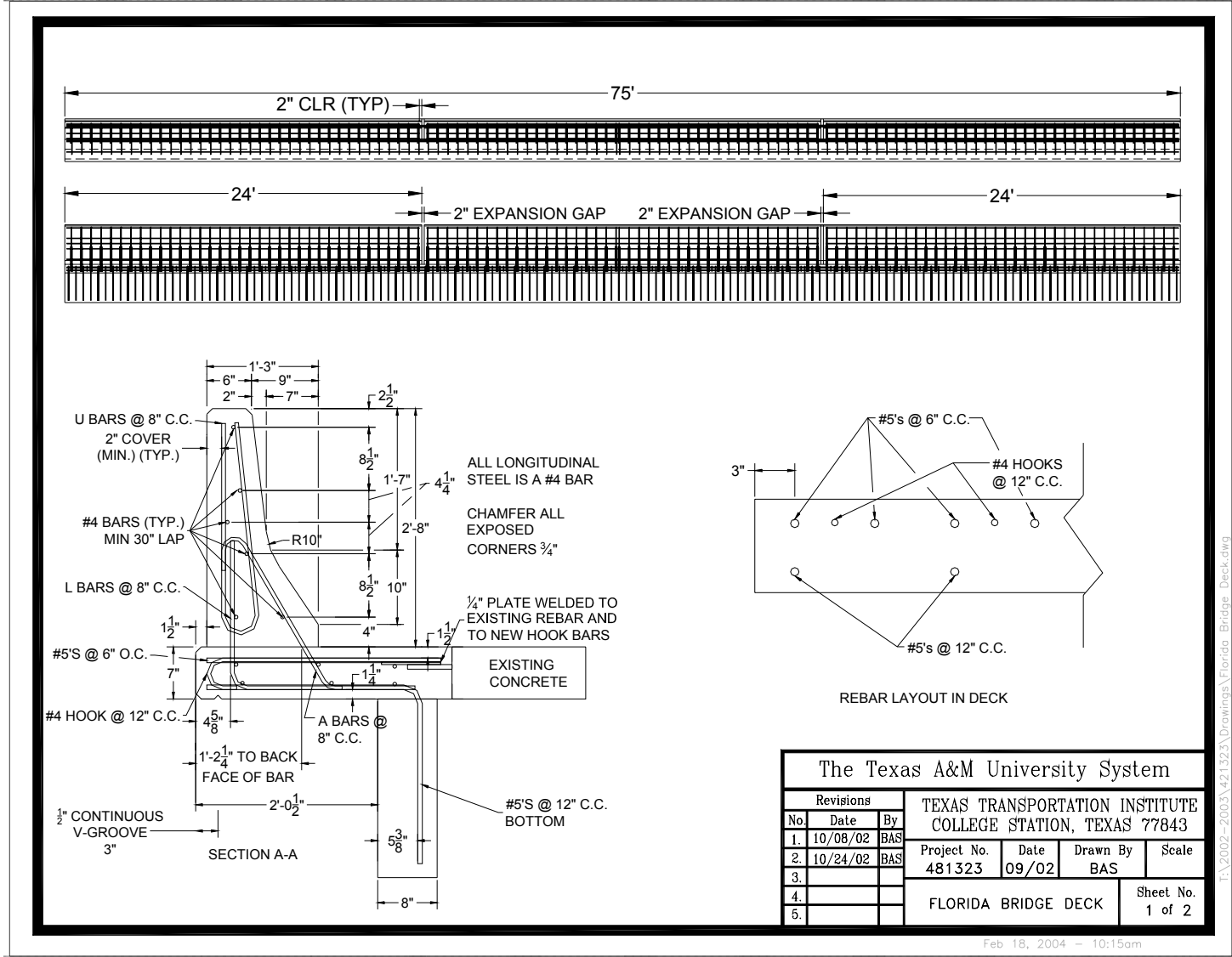


Figure 1. Cross Section of the Florida Jersey Safety Shaped Bridge Railing.



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Figure 2. Details of the Florida Jersey Safety Shaped Bridge Rail.

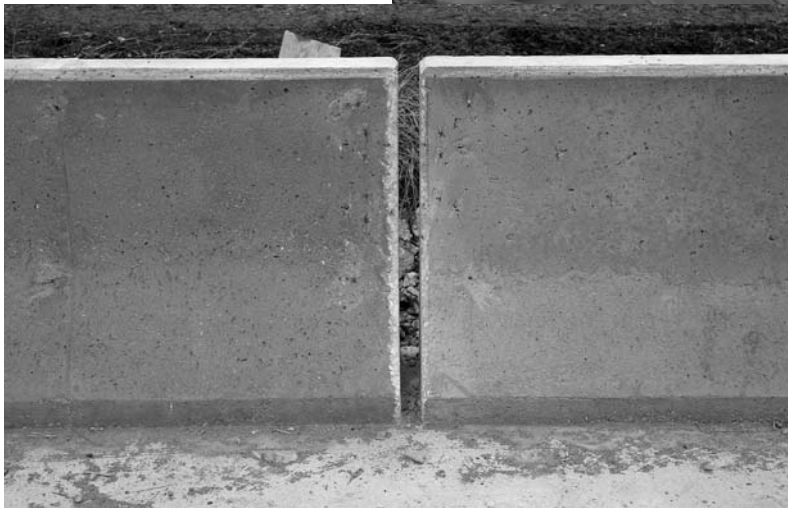


Figure 3. Florida Jersey Safety Shaped Bridge Rail before Test 421323-1.

Analysis of Bridge Railing

The *AASHTO LRFD Bridge Specifications* Section 13 sets forth test levels and the required test conditions for demonstrating a bridge rail meets a certain test level. The Appendix to Section 13 gives guidelines for designing bridge rails that will perform satisfactorily in full-scale crash tests. The yield line procedure in Section 13.3.1 was used to evaluate the Florida Jersey safety shaped bridge rail. Both the mid-span and end-span conditions were evaluated. [Appendix A](#) in this report includes results of the yield line analysis for both conditions.

CRASH TEST CONDITIONS

Three tests are required to evaluate longitudinal barriers, such as the Florida Jersey safety shaped bridge rail to TL-4 according to *NCHRP Report 350* and are described below.

NCHRP Report 350 test designation 4-10: An 1806-lb (820 kg) passenger car impacting the bridge rail at the critical impact point (CIP) of the length of need at a nominal speed and angle of 62.2 mi/h (100 km/h) and 20 degrees. The test is intended to evaluate occupant risk and post-impact trajectory.

NCHRP Report 350 test designation 4-11: A 4405-lb (2000 kg) pickup truck impacting the bridge rail at the CIP of the length of need at a nominal speed and angle of 62.2 mi/h (100 km/h) and 25 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 4405-lb (2000 kg) vehicle.

NCHRP Report 350 test designation 4-12: A 17,621-lb (8000 kg) single-unit truck impacting the bridge rail at the CIP of the length of need at a nominal speed and angle of 49.7 mi/h (80 km/h) and 15 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 17,621-lb (8000 kg) vehicle.

Test 4-10 was determined to be non-critical since the Jersey safety shaped barrier has been tested extensively with passenger cars and the focus of this research is structural capacity of this system. The first test reported herein corresponds to *NCHRP Report 350* test designation 4-12. The objective of this particular test was to evaluate the strength of the concrete parapet. According to *NCHRP Report 350* guidelines, the target impact point for this test was 4.9 ft (1.5 m) upstream of the joint. The second test performed was *NCHRP Report 350* test designation 4-11. Again, this test was to evaluate the strength of the section in safely containing and redirecting the pickup truck. The target impact point for this test was 3.9 ft (1.2 m) upstream of the joint.

The crash tests and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. [Appendix B](#) presents brief descriptions of these procedures.

EVALUATION CRITERIA

The crash tests performed were evaluated in accordance with *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.” Accordingly, researchers used the safety evaluation criteria from Table 5.1 of *NCHRP Report 350* to evaluate the crash tests reported herein.

CHAPTER 3. CRASH TEST RESULTS

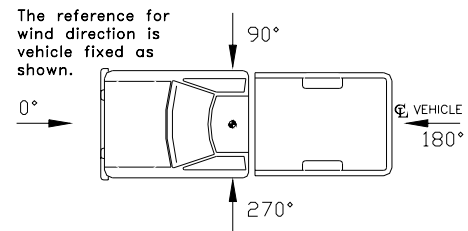
TEST NO. 421323-1 (NCHRP Report 350 TEST DESIGNATION 4-12)

Test Vehicle

A 1986 GMC 7000 single-unit truck, shown in Figures 4 and 5, was used for the crash test. Test inertia weight of the vehicle was 17,641 lb (8009 kg), and its gross static weight was 17,641 lb (8009 kg). The height to the lower edge of the vehicle bumper was 20.5 inches (521 mm), and the height to the upper edge of the bumper was 33.5 inches (851 mm). Figure 25 in Appendix C gives additional dimensions and information on the vehicle. 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.

Weather Conditions

The test was performed on the afternoon of February 18, 2003. Weather conditions at the time of testing were as follows: wind speed: 11 mi/h (18 km/h); wind direction: 0 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); temperature: 63 °F (17 °C); relative humidity: 79 percent.



Test Description

The single-unit van-truck, traveling at 50.6 mi/h (81.4 km/h), impacted the Florida bridge rail 5.6 ft (1.7 m) upstream of the first joint at an impact angle of 14.3 degrees.

Shortly after impact, the right front wheel began to ride up the face of the bridge rail, and at 0.029 second (s), the truck began to redirect. The right rear tire contacted the bridge rail at 0.266 s, and the tire blew out at 0.315 s. At 0.398 s, the front bumper of the truck reached the top of the bridge rail, and at 0.796 s, the bumper rode off the end of the bridge rail. The truck lost contact with the bridge rail at 0.908 s, and was traveling at a speed of 25.7 mi/h (41.4 km/h) and an exit angle of less than 5 degrees toward the bridge rail.

Brakes on the truck were applied shortly afterward, and the truck subsequently came to rest 107.6 ft (32.8 m) downstream of impact. Figures 27 and 28 in Appendix D show sequential photographs of the test period.



Figure 4. Vehicle/Installation Geometrics for Test 421323-1.

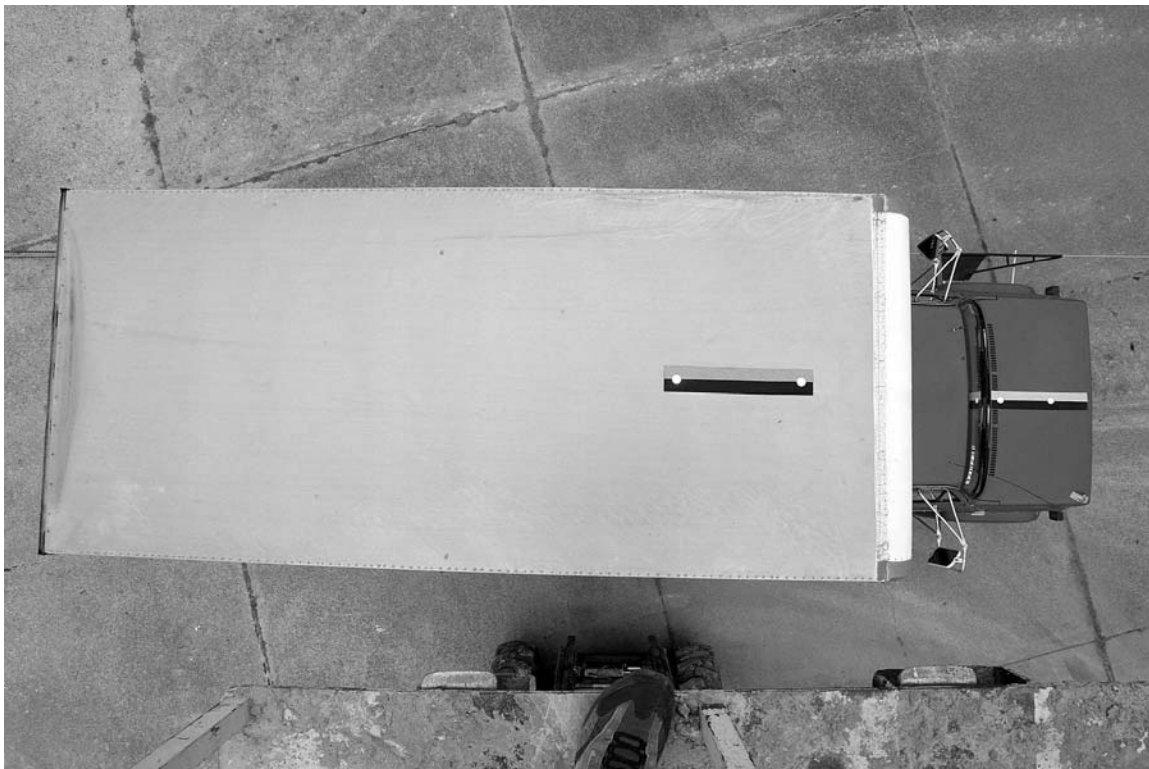


Figure 5. Vehicle before Test 421323-1.

Damage to Test Installation

Figures 6 and 7 show that the Florida bridge rail sustained cosmetic damage only. A small section on the edge of the first segment of bridge rail was chipped off, measuring 16.5 inches (420 mm) tall by 5.1 inches (130 mm) wide and starting 3.3 inches (85 mm) below the top of the segment. The truck contacted the bridge rail 5.6 ft (1.7 m) upstream of the joint and remained in contact with the bridge rail until it rode off the end.

Vehicle Damage

Figure 8 shows damage to the vehicle. The front axle was separated from the truck and the right rear wheel rim was bent. The lower right side of the cab and box were deformed. No measurable occupant compartment deformation occurred. Figure 9 shows photographs of the interior of the vehicle.

Occupant Risk Factors

Data from the accelerometer located at the vehicle center of gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 4.9 ft/s (1.5 m/s) at 0.259 s, the highest 0.010-s occupant ridedown acceleration was -3.9 g's or acceleration (g's) from 0.306 to 0.316 s, and the maximum 0.050-s average acceleration was -2.4 g's between 0.276 and 0.326 s. In the lateral direction, the occupant impact velocity was 6.6 ft/s (2.0 m/s) at 0.095 s, the highest 0.010-s occupant ridedown acceleration was -3.9 g's from 0.306 to 0.316 s, and the maximum 0.050-s average was -4.9 g's between 0.262 and 0.312 s. Figure 10 summarizes these data and other pertinent information from the test. Figures 32 through 39 in Appendix E present the vehicle angular displacements and accelerations versus time traces.

Assessment of Crash 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.*

Result: The Florida bridge rail contained and redirected the single-unit truck. The truck did not penetrate, underride, or override the installation. Minimal movement of the bridge rail was noted during the test with no permanent deformation.



Figure 6. After Impact Trajectory Path for Test 421323-1.

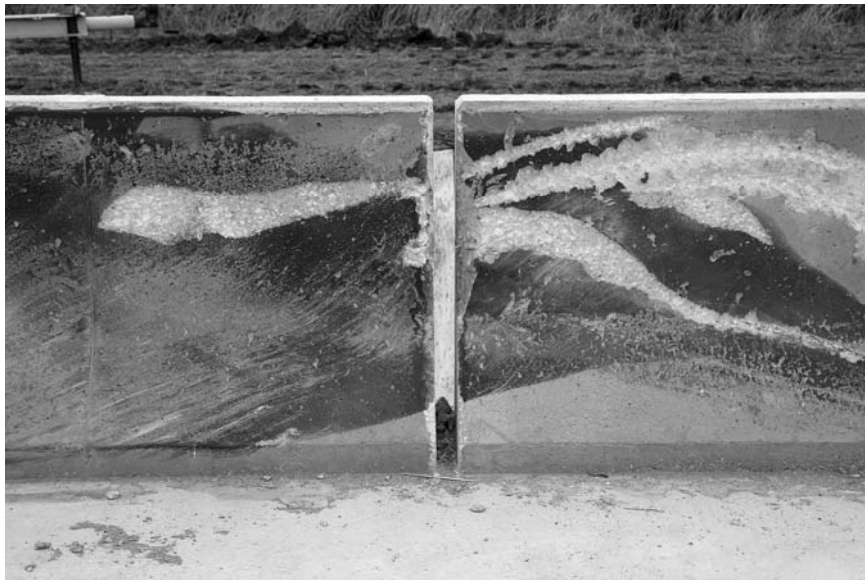


Figure 7. Installation after Test 421323-1.



Figure 8. Vehicle after Test 421323-1.

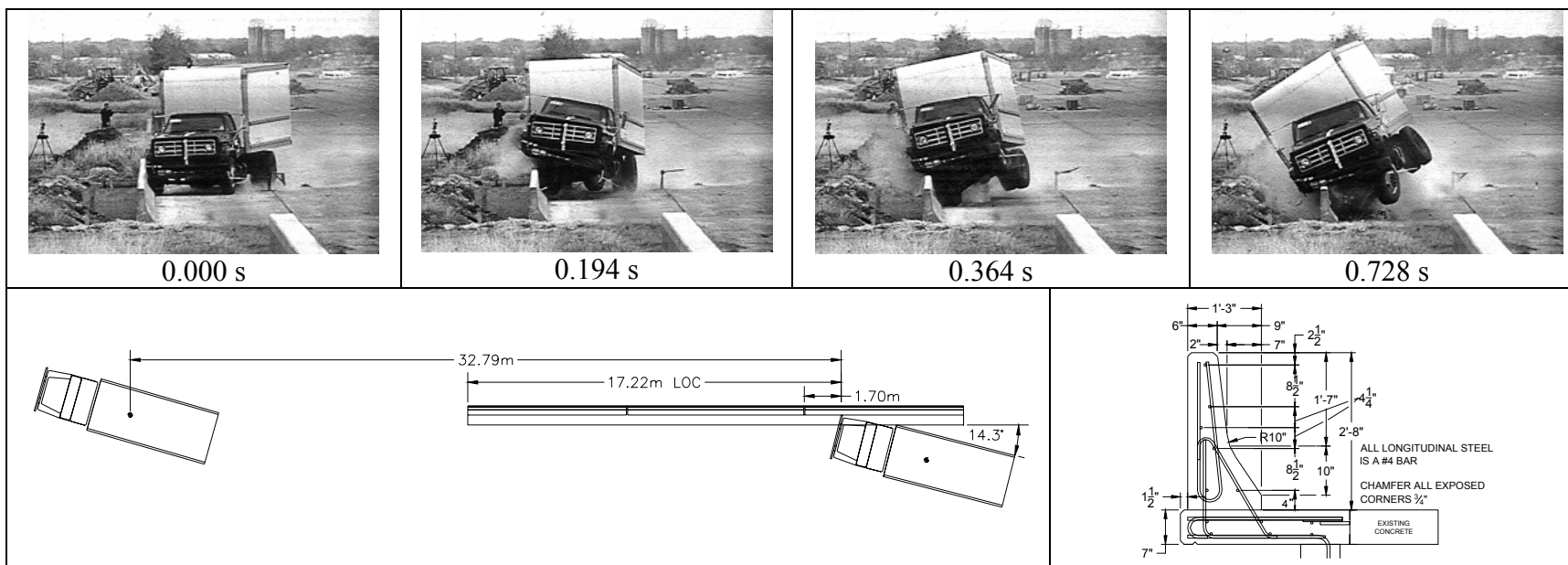


Before test



After test

Figure 9. Interior of Vehicle for Test 421323-1.



General Information		Impact Conditions		Test Article Deflections	
Test Agency	Texas Transportation Institute	Speed (mi/h (km/h)).....	50.6 (81.4)	Dynamic.....	0
Test No.	421323-1	Angle (deg).....	14.3	Permanent.....	0
Date.....	02-18-2003	Exit Conditions		Working Width.....	5.9 ft (1.8 m)
Test Article		Speed (mi/h (km/h)).....	25.7 (41.4)	Vehicle Damage	
Type	Bridge Rail	Angle (deg).....	~5	Exterior	
Name.....	Florida NJ Shaped Bridge Rail	Occupant Risk Values		VDS.....	N/A
Installation Length.....	75.0 ft (23 m)	Impact Velocity (ft/s (m/s))		CDC.....	N/A
Material or Key Elements.....	32 in (813 mm) tall Jersey Safety Shaped Bridge Rail	Longitudinal.....	4.9 (1.5)	Maximum Exterior	
Soil Type and Condition		Lateral.....	6.6 (2.0)	Vehicle Crush.....	13.7 in
Concrete, Dry		THIV (km/h).....	7.9	Interior	(350 mm)
Test Vehicle		Ridedown Accelerations (g's)		OCDI.....	N/A
Type	Production	Longitudinal.....	-3.9	Maximum Occupant	
Designation	8000S	Lateral.....	-12.7	Compartment Deformation.....	0
Model.....	1986 GMC Sierra 7000	PHD (g's).....	12.8	Post-Impact Behavior	
Mass		ASI.....	0.56	(during 1.0 sec after impact)	
Curb.....	11,180 lb (5076 kg)	Max. 0.050-s Average (g's)		Max. Yaw Angel (deg).....	-7.6
Test Inertial.....	17,641 lb (8009 kg)	Longitudinal.....	-2.4	Max. Pitch Angle (deg).....	-8.1
Dummy.....	No dummy	Lateral.....	-4.9	Max. Roll Angle (deg).....	30.7
Gross Static.....	17,641 lb (8009 kg)	Vertical.....	-2.4		

Figure 10. Summary of Results for NCHRP Report 350 Test 4-12 on the Florida Jersey Safety Shaped Bridge Rail.

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.*

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No measurable deformation of the occupant compartment occurred.

- G. It is preferable, although not essential, that the vehicle remain upright during and after collision.*

Result: The single-unit truck remained upright during and after the collision period.

Vehicle Trajectory

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

Result: The single-unit truck did not intrude into adjacent traffic lanes.

- 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 attainable, but estimated exit angle was less than 5 degrees toward the bridge rail.

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 (4). Criteria underlined below reflect the results for the crash test reported herein.

Passenger Compartment Intrusion

1. Windshield Intrusion

a. No windshield contact

b. Windshield contact, no damage

c. Windshield contact, no intrusion

d. Device embedded in windshield, no significant intrusion

e. Complete intrusion into passenger compartment

f. Partial intrusion into passenger compartment

2. Body Panel Intrusion

yes or no

Loss of Vehicle Control

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

Physical Threat to Workers or Other Vehicles

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

No debris 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
- 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. Major structural damage
- 3. Device Damage
 - a. None
 - b. Superficial
 - c. Substantial, but can be straightened
 - d. Shattered, remained intact but partially dislodged
 - e. Large portion removed
 - f. Completely removed
 - d. Substantial, replacement parts needed for repair
 - e. Cannot be repaired

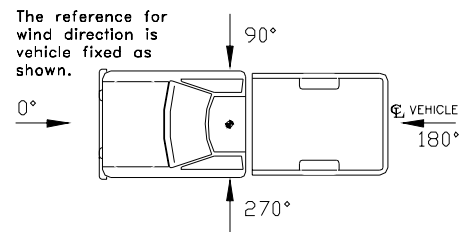
TEST NO. 421323-2 (NCHRP Report 350 TEST DESIGNATION 4-11)

Test Vehicle

Figures 11 and 12 show the 1998 Chevrolet pickup truck used for the crash test. Test inertia weight of the vehicle was 4544 lb (2063 kg), and its gross static weight was 4544 lb (2063 kg). The height to the lower edge of the vehicle bumper was 16.3 inches (415 mm), and the height to the upper edge of the bumper was 25.0 inches (635 mm). Figure 27 in Appendix C gives additional dimensions and information on the vehicle. 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.

Weather Conditions

The test was performed on the afternoon of March 18, 2003. Weather conditions at the time of testing were as follows: wind speed: 2 mi/h (3 km/h); wind direction: 200 degrees with respect to the vehicle (vehicle was traveling in a northwesterly direction); temperature: 66 °F (19 °C); relative humidity: 62 percent.



Test Description

The 4544-lb (2063 kg) pickup truck, traveling at a speed of 61.1 mi/h (98.3 km/h), impacted the Florida Jersey safety shaped bridge rail 4.1 ft (1.25 m) upstream of the joint at an impact angle of 26.4 degrees.

Shortly after impact, the left front tire began to ride up the face of the bridge rail, and by 0.047 s after impact, the vehicle began to redirect. The left rear tire of the vehicle contacted the bridge rail at 0.168 s, and the rear bed of the vehicle contacted the bridge rail at 0.224 s. At 0.230 s, the vehicle was traveling parallel with the bridge rail at a speed of 48.1 mi/h (77.4 km/h). The left front tire lost contact with the bridge rail at 0.265 s. At 0.396 s, the rear of the vehicle lost contact with the bridge rail and the vehicle was traveling at a speed of 49.8 mi/h (80.1 km/h) and an exit angle of 6.4 degrees.

Brakes on the vehicle were applied at approximately 1.5 s after impact, and the vehicle subsequently came to rest 229 ft (69.8 m) downstream of impact and 56 ft (17.2 m) forward of the traffic face of the bridge rail. Figures 30 and 31 in Appendix D display sequential photographs of the collision period.



Figure 11. Vehicle/Installation Geometrics for Test 421323-2.



Figure 12. Vehicle before Test 421323-2.

Damage to Test Installation

Figures 13 and 14 show that the Florida bridge rail sustained moderate structural damage on either side of the joint just upstream of impact. A small section on each of the edges of the first and second segments of bridge rail were cracked, extending a maximum distance of 42.9 inches (1090 mm) upstream on the first segment and a maximum distance of 33.7 inches (855 mm) downstream on the second segment. A hairline crack in the deck radiated downward from the field side corner of the downstream segment and extended 6.0 inches (152 mm) under the deck. Maximum dynamic deflection was not attainable, and maximum permanent deformation was 0.75 inches (19 mm). The truck contacted the bridge rail 4.1 ft (1.25 m) upstream of the joint and remained in contact with the bridge rail for a distance of 17.2 ft (5.23 m).

Vehicle Damage

Figure 15 shows the damage to the vehicle. Structural damage was imparted to the left outer tie rod end, lower A-arm and spindle, front of the frame rail, and the firewall and floor pan. The inner rim of the left wheel separated from the outer rim. Also damaged were the front bumper, grill, radiator, left front quarter panel, left door, left rear exterior bed, left rear tire, and the right rear of the bed. The windshield also sustained stress cracks and the door glass was broken out. Maximum exterior crush to the pickup was 25.2 inches (640 mm) in the side plane at the left front corner just above bumper height. Maximum occupant compartment deformation was 3.4 inches (87 mm) in the left side firewall area. Figure 16 shows photographs of the interior of the vehicle. Tables 3 and 4 in Appendix C show exterior crush profile and occupant compartment deformation.

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 in *NCHRP Report 350*. In the longitudinal direction, occupant impact velocity was 19.4 ft/s (5.9 m/s) at 0.095 s, maximum 0.010-s ridedown acceleration was -10.2 g's from 0.095 to 0.105 s, and the maximum 0.050-s average was -9.0 g's between 0.047 and 0.097 s. In the lateral direction, the occupant impact velocity was 9.1 m/s at 0.095 s, the highest 0.010-s occupant ridedown acceleration was 5.5 g's from 0.242 to 0.252 s, and the maximum 0.050-s average was 15.3 g's between 0.045 and 0.095 s. Figure 17 presents these data and other information pertinent to the test. Figures 40 through 46 in Appendix E show vehicle angular displacements and accelerations versus time traces.



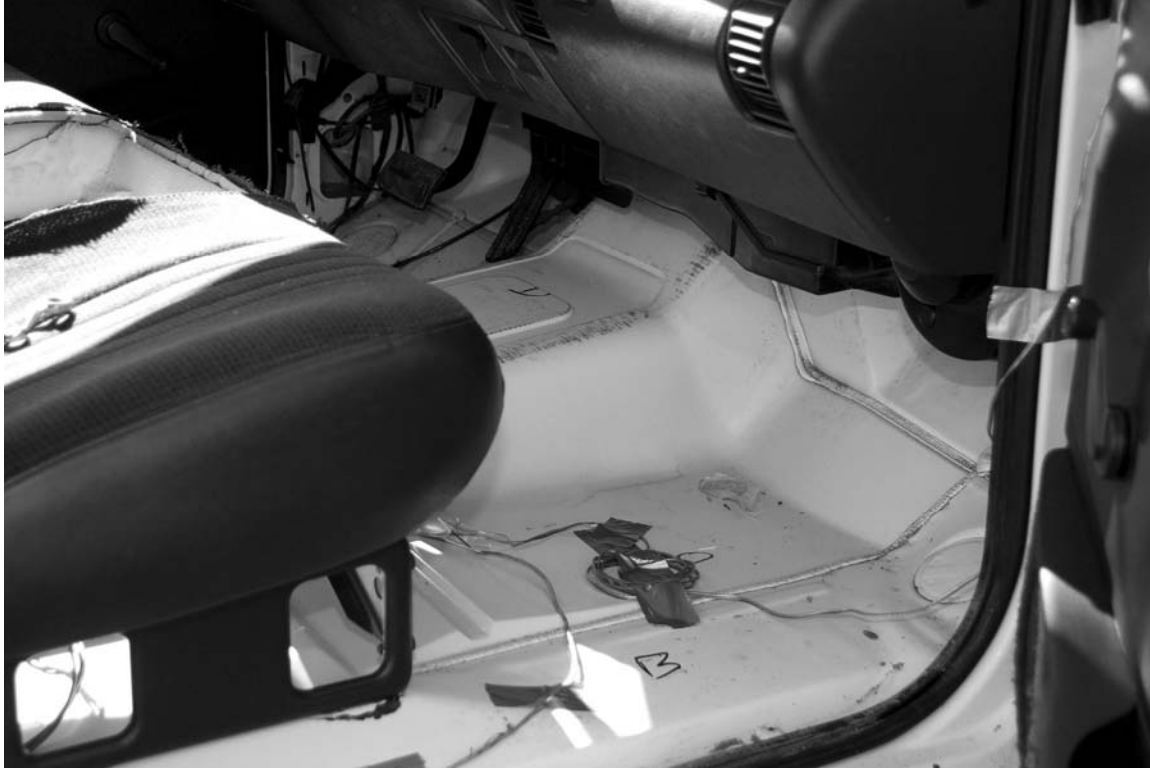
Figure 13. After Impact Trajectory Path for Test 421323-2.



Figure 14. Installation after Test 421323-2.



Figure 15. Vehicle after Test 421323-2.

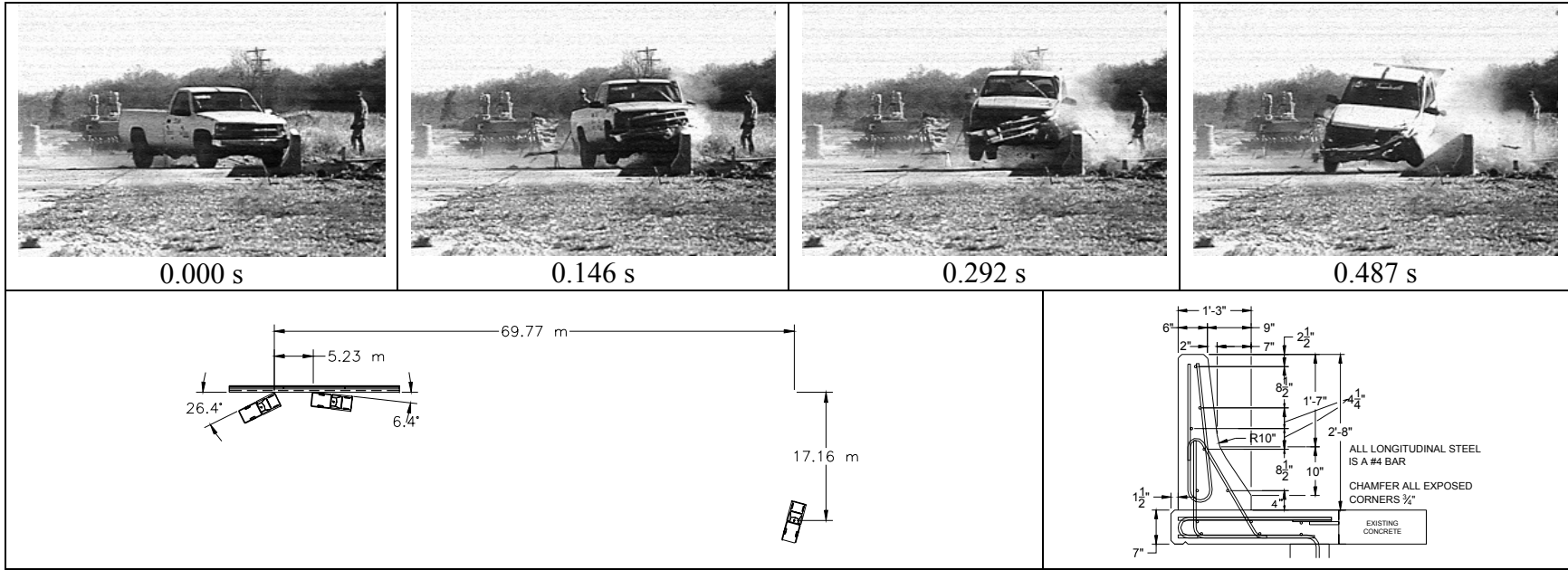


Before Test



After test

Figure 16. Interior of Vehicle for Test 421323-2.



General Information		Impact Conditions		Test Article Deflections	
Test Agency	Texas Transportation Institute	Speed (mi/h (km/h)).....	61.1 (98.3)	Dynamic.....	N/A
Test No.	421323-2	Angle (deg).....	26.4	Permanent.....	0.75 in (19 mm)
Date.....	03-18-2003	Exit Conditions		Working Width.....	28.4 in (723 mm)
Test Article		Speed (mi/h (km/h)).....	49.8 (80.1)	Vehicle Damage	
Type	Bridge Rail	Angle (deg).....	6.4	Exterior	
Name.....	Florida NJ Shaped Bridge Rail	Occupant Risk Values		VDS.....	
Installation Length.....	75.0 ft (23 m)	Impact Velocity (ft/s (m/s))		CDC.....	
Material or Key Elements.....	32 in (813 mm) tall Jersey Safety Shaped Bridge Rail	Longitudinal.....	19.4 (5.9)	Maximum Exterior	
Soil Type and Condition		Lateral.....	29.9 (9.1)	Vehicle Crush.....	
Concrete, Dry		THIV (km/h).....	37.6	25.2 in (640 mm)	
Test Vehicle		Ridedown Accelerations (g's)		Interior	
Type	Production	Longitudinal.....	-10.2	OCDI.....	
Designation	2000P	Lateral.....	5.5	Maximum Occupant	
Model	1998 Chevrolet 2500	PHD (g's).....	12.2	Compartment Deformation.....	
Mass		ASI.....	1.86	3.4 in (87 mm)	
Curb.....	4789 lb (2174 kg)	Max. 0.050-s Average (g's)		Post-Impact Behavior	
Test Inertial.....	4544 lb (2063 kg)	Longitudinal.....	-9.0	(during 1.0 sec after impact)	
Dummy.....	N/A	Lateral.....	15.3	Max. Yaw Angel (deg).....	
Gross Static.....	4544 lb (2063 kg)	Vertical.....	-7.2	51.1	
				Max. Pitch Angle (deg).....	
				-19.3	
				Max. Roll Angle (deg).....	
				-18.6	

Figure 17. Summary of Results for NCHRP Report 350 Test 4-11 on the Florida Jersey Safety Shaped Bridge Rail.

Assessment of Crash 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.

Result: The Florida bridge rail contained and redirected the pickup truck. The truck did not penetrate, underride, or override the installation. Minimal movement of the bridge rail was noted during the test with maximum permanent deformation of 0.75 inches (19 mm).

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.

Result: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 3.4 inches (87 mm) in the left side firewall area.

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

Result: The pickup truck remained upright during and after the collision period.

Vehicle Trajectory

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

Result: The pickup truck came to rest 229 ft (69.8 m) downstream of impact and 56 ft (17.2 m) forward of the traffic face of the bridge rail.

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

3. *Device Damage*

a. *None*

b. *Superficial*

c. *Substantial, but can be straightened*

d. *Substantial, replacement parts
needed for repair*

e. *Cannot be repaired*

CHAPTER 4. STATIC LOAD TESTS

STATIC LOAD TESTS ON SAFETY SHAPED TEST INSTALLATION

The *AASHTO LRFD* design method analysis indicated the potential for poor performance in the full-scale crash test. Static tests replicating the loads used in the design procedure in *LRFD* were performed to verify actual capacities of the bridge parapet. The static load tests were performed with a hydraulic ram attached to a braced load frame, pushing on a load cell, and placed against a spreader beam, W12×50 (W310×74), 42 inches (1067 mm) long. A thin sloped piece of timber was placed on the face of the spreader beam to create a vertical pushing face for the load cell and ram. It also minimized stress concentrations due to surface imperfections in the parapet. [Figure 18](#) shows the test setup.



Figure 18. Test Setup for Static Load Testing.

Test S-1

Test S-1 was on the upstream end of the test installation and was intended to represent the loading at a construction joint. The maximum load attained was 35.1 kips (156 kN). The anticipated load from the yield line analysis was 41.5 kips (185 kN). Subsequent review of the installation showed the last stirrup was approximately 6 inches (152 mm) from the end of the parapet wall and likely contributed to the lower fracture load. Figure 19 shows the results of the static test S-1. Figure 20 shows the failure mode.

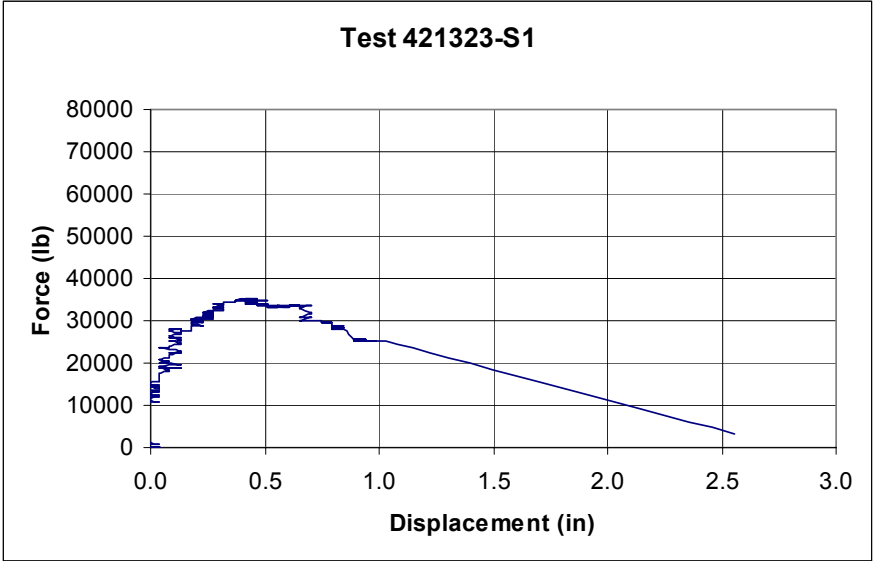


Figure 19. Results of Test 421323-S1.



Figure 20. Failure Mode for Test 421323-S1.

Test S-2

Visual inspection of the bridge parapet after the TL-4 test did not reveal any perceptible cracking. Since the test setup was readily available, the impact region of the barrier was statically tested to failure at the expansion joint. The maximum load was 45.1 kips (201 kN) and the test results are shown in Figure 21 below. Figure 22 shows the failure mode.

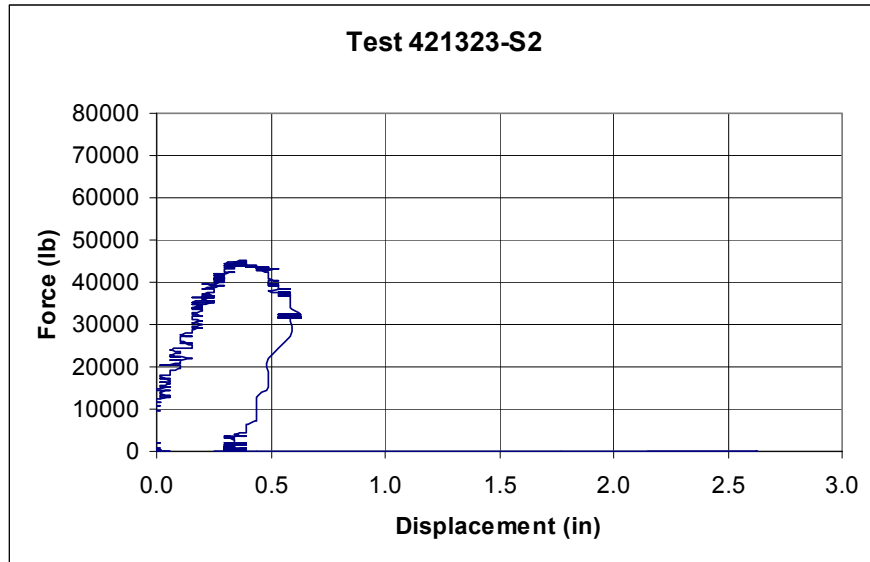


Figure 21. Results for Test 421323-S2.

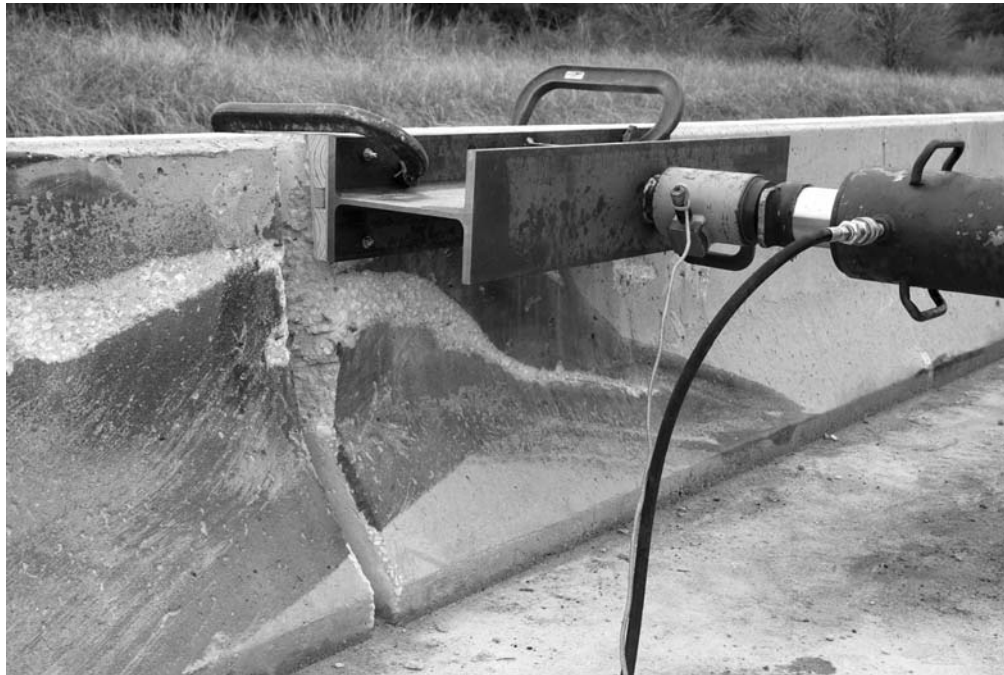


Figure 22. Failure Mode for Test 421323-S2.

Test S-3

Test S-3 was at mid-span of the undamaged rail section as shown in [Figure 23](#). The predicted failure load was 62.1 kips (276 kN). The maximum load obtained was 73.1 kips (325 kN). [Figure 24](#) shows test results. Yield lines were confined to the upper, slender portion of the parapet as shown in [Figure 25](#).



Figure 23. Setup for Test 421323-S3.

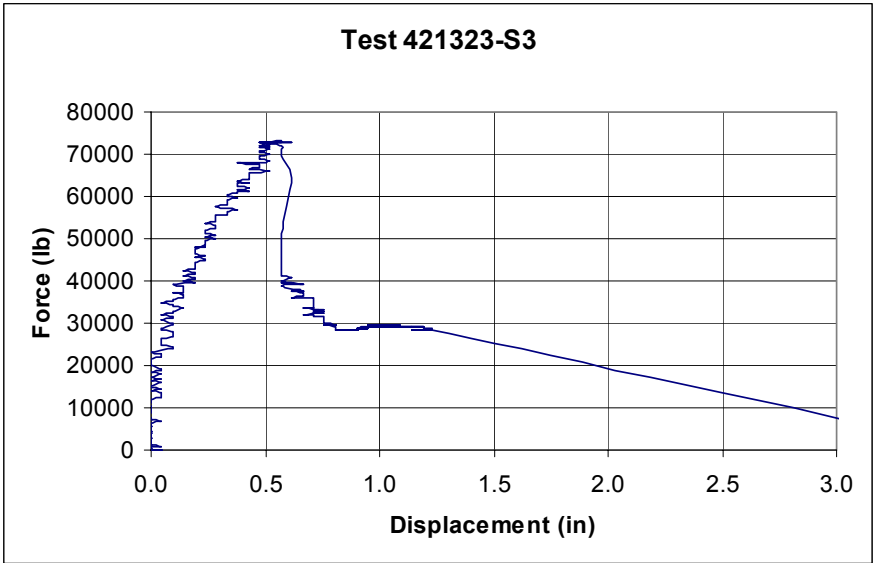


Figure 24. Results of Test 421323-S3.



Figure 25. Failure Mode for Test 421323-S3.

CHAPTER 5. SUMMARY AND CONCLUSIONS

SUMMARY OF CRASH TEST RESULTS

NCHRP Report 350 Test Designation 4-12

The Florida bridge rail contained and redirected the single-unit truck. The truck did not penetrate, underride, or override the installation. Minimal movement of the bridge rail was noted during the test with no permanent deformation. No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No measurable deformation of the occupant compartment occurred. The single-unit truck remained upright during and after the collision period. The single-unit truck did not intrude into adjacent traffic lanes. Exit angle at loss of contact was not attainable, but estimated exit angle was less than 5 degrees with trajectory heading referenced toward the bridge rail.

NCHRP Report 350 Test Designation 4-11

The Florida bridge rail contained and redirected the 4405-lb (2000 kg) pickup truck. The truck did not penetrate, underride, or override the installation. Minimal movement of the bridge rail was noted during the test with maximum permanent deformation of 0.75 inches (19 mm). No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 3.4 inches (87 mm) in the left side firewall area. The pickup truck remained upright during and after the collision period. The pickup truck came to rest 229 ft (69.8 m) downstream of impact and 56 ft (17.2 m) forward of the traffic face of the bridge rail. The longitudinal occupant impact velocity was 19.4 ft/s (5.9 m/s) and the longitudinal ridedown acceleration was -10.2 g's. Exit angle at loss of contact was 6.4 degrees, which was 24 percent of the impact angle.

SUMMARY OF STATIC TEST RESULTS

With successful redirection of both the single unit truck and the pickup, the parapet was deemed acceptable and remaining tasks of the project for further analysis and possible retrofits became unnecessary. Since the *AASHTO LRFD* design method had indicated the potential for poor performance in the full-scale crash test, static tests replicating the loads used in the design procedure in *LRFD* were performed to verify actual capacities of the bridge parapet. The only undamaged portions of the parapet were at mid-spans and the outside ends of the parapets. The end of the installation opposite from the crash test impact was selected for the static load test at a joint and the actual load at breakage of the parapet at the expansion joint was 35.1 kips (156 kN) while the predicted load was 41.1 kips (183 kN). Since the actual load did not achieve the anticipated design load, the damaged concrete was removed and the end stirrup was found to be approximately 6 inches (152 mm) from the end of the parapet. This location was not originally

intended for impact or static testing so the inspection prior to concrete placement did not reveal the deficiency.

The damage from the single-unit truck impact at an expansion joint appeared to be limited to surface scarring of the concrete – no visible cracks were identified. A static test at this location would serve two purposes: 1) it would verify that visual inspections may be acceptable for determining structural integrity after an impact and 2) stirrup placement was verified before concrete placement and actual load should more closely match the predicted design load. The ultimate static load at this location was 45.1 kips (201 kN), predicted was again 41.1 kips (183 kN). Therefore the actual load exceeded the yield line analysis prediction by approximately 10 percent.

CONCLUSIONS

The Florida bridge rail performed acceptably according to the specifications of *NCHRP Report 350* test designations 4-12 and 4-11, as shown in Tables 1 and 2. In test 4-12 with the single-unit van-truck, the parapet received cosmetic damage only. The subsequent static load test at the impact location failed the parapet at 45.1 kips (201 kN). The *AASHTO LRFD Bridge Design Specifications* uses a 54-kip (240 kN) design load for single-unit trucks. Since the parapet was not structurally damaged in the TL-4 test with the single-unit truck, further research should be undertaken to account for the reduced loads apparently imparted by the impacting single-unit truck.

IMPLEMENTATION STATEMENT

No field retrofits or replacements of the Florida Jersey safety shaped bridge rails, depicted in the Florida DOT Index 799, are warranted since the most critical 32-inch (813 mm) Jersey safety shaped railing complied with the requirements of the *AASHTO LRFD Bridge Design Specifications* and *NCHRP Report 350* Test Level 4.

**Table 1. Performance Evaluation Summary for NCHRP Report 350 Test 4-12
on the Florida Jersey Safety Shaped Bridge Rail.**

Test Agency: Texas Transportation Institute		Test No.: 421323-1	Test Date: 02/18/2003
NCHRP Report 350 Test 4-12 Evaluation Criteria		Test Results	Assessment
<u>Structural Adequacy</u>			
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>	The Florida bridge rail contained and redirected the single-unit truck. The truck did not penetrate, underride, or override the installation. Minimal movement of the bridge rail was noted during the test, and there was no measurable permanent deformation.	Pass
<u>Occupant Risk</u>			
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>	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. No measurable deformation of the occupant compartment occurred.	Pass
G.	<i>It is preferable, although not essential, that the vehicle remain upright during and after collision.</i>	The single-unit truck remained upright during and after the collision period.	Pass
<u>Vehicle Trajectory</u>			
K.	<i>After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</i>	The vehicle did not intrude into adjacent traffic lanes.	Pass
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>	Exit angle at loss of contact was not attainable, but was estimated to be less than 5 degrees toward the bridge rail.	Pass

*Criteria K and M are preferable, not required.

**Table 2. Performance Evaluation Summary for NCHRP Report 350 Test 4-11
on the Florida Jersey Safety Shaped Bridge Rail.**

Test Agency: Texas Transportation Institute	Test No.: 421323-2	Test Date: 03/18/2003
NCHRP Report 350 Test 4-11 Evaluation Criteria	Test Results	Assessment
<u>Structural Adequacy</u>		
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>	The Florida bridge rail contained and redirected the pickup truck. The truck did not penetrate, underride, or override the installation. Maximum permanent deformation of the bridge rail was 0.75 inches (19 mm).	Pass
<u>Occupant Risk</u>		
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>	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum deformation of the occupant compartment was 3.4 inches (87 mm) in the left side firewall area.	Pass
F. <i>The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</i>	The pickup truck remained upright during and after the collision period.	Pass
<u>Vehicle Trajectory</u>		
K. <i>After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</i>	The pickup truck came to rest 229 ft (69.8 m) downstream of impact and 56 ft (17.2 m) forward of the traffic face of the bridge rail.	Fail
L. <i>The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.</i>	The longitudinal occupant impact velocity was 19.4 ft/s (5.9 m/s) and the longitudinal ridedown acceleration was -10.2 g's.	Pass
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>	Exit angle at loss of contact was 6.4 degrees, which was 24 percent of the impact angle.	Pass

*Criteria K and M are preferable, not required.

REFERENCES

1. American Association of State Highway and Transportation Officials. *LRFD Bridge Design Specifications*, AASHTO Subcommittee on Bridges and Structures, Washington, D.C., May 2001.
2. K. K. Mak and W. L. Campise. Test and Evaluation of Ontario “Tall Wall” Barrier with an 80,000-Pound Tractor-Trailer, Texas Transportation Institute, Contract No. 4221-9089-534 for Ontario Ministry of Transportation, College Station, Texas, 1990.
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. Federal Highway Administration Memorandum from the Director, Office of Engineering, entitled: “ACTION: Identifying Acceptable Highway Safety Features,” dated July 25, 1997.

APPENDIX A. YIELD LINE ANALYSIS OF FDOT BRIDGE RAILS



PAGE 1 of 6

JOB NO. 421323

Date: 02-17-03

SUBJECT Florida Bridge Rail Analysis

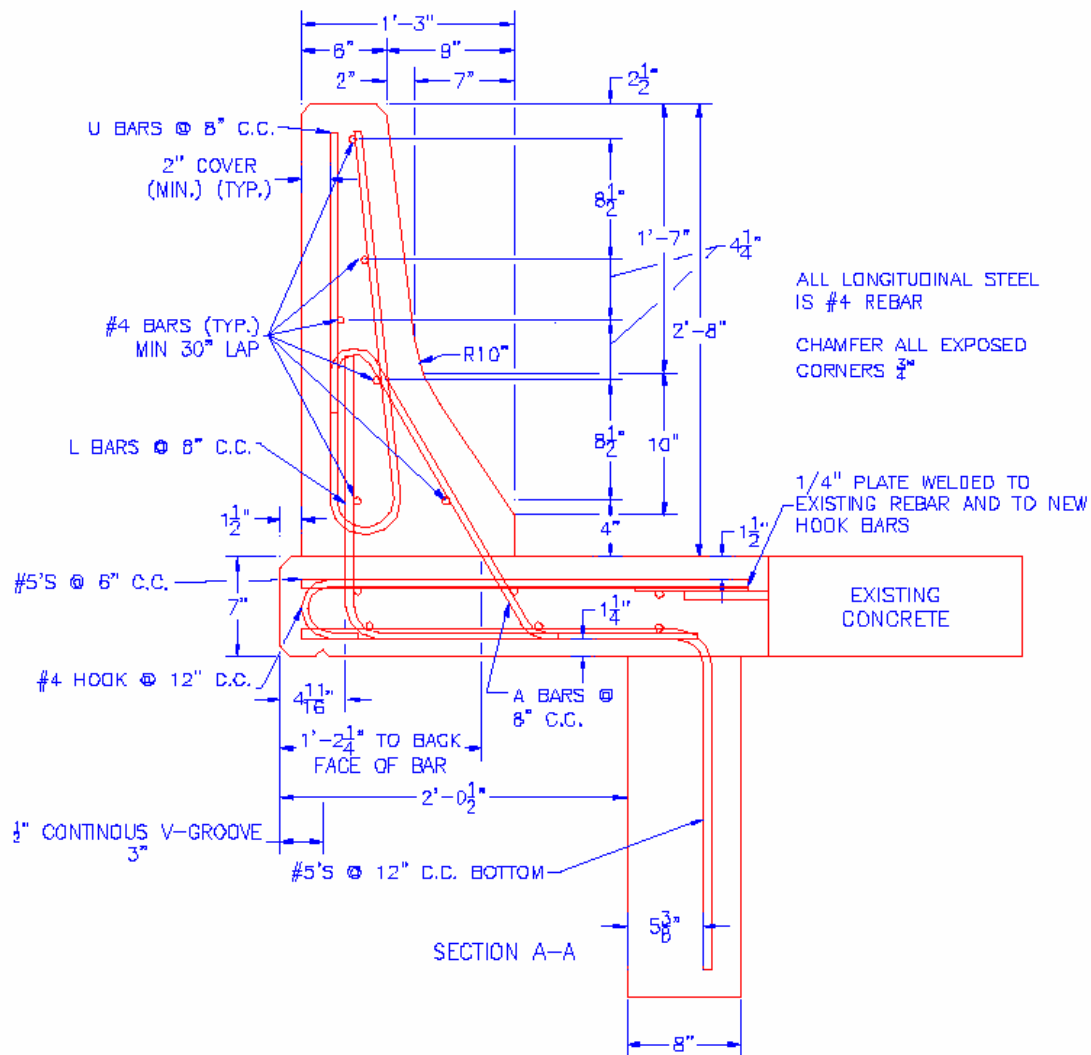
BY: W. Williams

Impact @ 2" Wide Joint

CKD: _____

CLIENT FLADOT

1.) Given Information: 1.) Florida DOT Barrier Details as shown:





SUBJECT Florida Bridge Rail Analysis
Impact @ 2" Wide Joint
CLIENT FLADOT

BY: W. Williams
CKD: _____

2.) Design Information & Material Properties:

$TL_{3load} := 54\text{kips}$

$f_c := 4100\text{psi}$ Compressive strength of concrete

$f_y := 60\text{ksi}$ Yield Strength of Reinforcing Steel

$L_t := 3.5\text{ft}$

$H_w := 19\text{in}$... Height of impacted length above radius

SUBJECT Florida Bridge Rail Analysis BY: W. Williams
Impact @ 2" Wide Joint CKD: _____
 CLIENT FLADOT

3.) Calculate the bending Capacity of the Rail about the Longitudinal Axis: M_c , (K-F/F):

$f_y = 60 \text{ ksi}$ Yield strength of rebar
 $f'_c = 4100 \text{ psi}$ Compressive strength of concrete
 $A_{sc} := 0.20 \text{ in}^2 \cdot \frac{12}{8}$ Vertical #4 Bars @ 8" O.C. $A_{sc} = 0.3 \text{ in}^2$
 $b_c := 12 \text{ in}$ Unit width of wall, (in)
 $a_c := \frac{A_{sc} \cdot f_y}{0.85 \cdot f'_c \cdot b_c}$ $a_c = 0.43 \text{ in}$

$d_c := \frac{5.75 \text{ in} + 0 \text{ in}}{1}$ "approximate weighted average distance to tension steel from radius to top steel in barrier.

$d_c = 5.75 \text{ in}$

Calculate M_c :

with: $d_c = 5.75 \text{ in}$ $\phi := 1.0$
 $A_{sc} = 0.3 \text{ in}^2$
 $f_y = 60 \text{ ksi}$
 $a_c = 0.43 \text{ in}$

Therefore:

$M_c := \frac{(\phi \cdot A_{sc} \cdot f_y) \cdot \left(d_c - \frac{a_c}{2} \right)}{\text{ft}}$ Ratio M_c to include 12" Wall unit length.

$M_c = 8.3 \text{ ft}^{-1} \text{ kips} \cdot \text{ft}$

FLexural Resistance of 12" width specified in Article A13.4.2 (K-FT/FT)

SUBJECT Florida Bridge Rail Analysis
Impact @ 2" Wide Joint
 CLIENT FLADOT

BY: W. Williams
 CKD: _____

4.) Calculate the bending Capacity of the Wall about the Vertical Axis: M_w , (K-F):

$A_{sw} := 0.2 \text{ in}^2 \cdot 3$... 3 Longitudinal Tension Bars in the impacted area.

$f_y = 60 \text{ ksi}$

$H_w = 19 \text{ in}$

$b_c = 1 \text{ ft}$

$a_w := \frac{A_{sw} \cdot f_y}{0.85 \cdot f'_c \cdot b_c}$

$f'_c = 4.1 \times 10^3 \text{ psi}$

$a_w = 0.86 \text{ in}$

$d_w := 3 \text{ in} + \frac{9}{16} \text{ in}$..distance to longitudinal tension steel in curb

$d_w = 3.56 \text{ in}$

Calculate M_w :

with:

$d_w = 3.56 \text{ in}$

$H_w = 1.58 \text{ ft}$

$A_{sw} = 0.6 \text{ in}^2$

$\phi = 1$

$f_y = 60 \text{ ksi}$

$a_w = 0.86 \text{ in}$

Therefore:

$$M_w := \frac{\left[\phi \cdot A_{sw} \cdot f_y \cdot \left(d_w - \frac{a_w}{2} \right) \right]}{H_w}$$

$M_w = 5.93 \text{ ft}^{-1} \text{ kips} \cdot \text{ft}$

Flexural Resistance of Wall
in (K-FT/FT)

SUBJECT Florida Bridge Rail Analysis
Impact @ 2" Wide Joint
CLIENT FLADOT

BY: W. Williams
CKD: _____

5.) Additional Flexural Ristance from Beam Action in top of Rail: M_b , (K-F):

$$A_{sw} := 0.0 \text{ in}^2 \cdot 2 \quad \dots \text{ No additional beam action provided!}$$

$$f_y = 60 \text{ ksi}$$

$$a_w := \frac{A_{sw} \cdot f_y}{0.85 \cdot f_c \cdot b_c}$$

$$a_w = 0 \text{ in}$$

$$d_w := 19.5 \text{ in} - 2 \text{ in} \quad \dots \text{distance to longitudinal tension steel in curb}$$

$$d_w = 17.5 \text{ in}$$

Calculate M_b :

with:

$$d_w = 17.5 \text{ in} \quad H_w = 19 \text{ in}$$

$$A_{sw} = 0 \text{ in}^2 \quad \phi = 1$$

$$f_y = 60 \text{ ksi}$$

$$a_w = 0 \text{ in}$$

Therefore:

$$M_b := \left[\phi \cdot A_{sw} \cdot f_y \cdot \left(d_w - \frac{a_w}{2} \right) \right]$$

$$M_b = 0 \text{ kips} \cdot \text{ft}$$

FLexural Resistance of beam in top of curb
in (K-FT)

SUBJECT Florida Bridge Rail Analysis
Impact @ 2" Wide Joint

BY: W. Williams

CKD: _____

CLIENT FLADOT

6.) Determine Ultimate Resistance of Wall at MidSpan:

Calculate L_c ~ Critical length of yield line failure pattern:

with:

$$M_b = 0 \text{ kips} \cdot \text{ft} \quad \dots \text{ No additional beam action resistance}$$

$$M_c = 8.3 \frac{\text{kips} \cdot \text{ft}}{\text{ft}} \quad \text{Calculated Wall Strengths}$$

$$M_w = 5.93 \frac{\text{kips} \cdot \text{ft}}{\text{ft}}$$

$$H := H_w$$

$$H = 19 \text{ in} \quad \dots \text{ Height of rail, (ft.)}$$

Longitudinal length of distribution of impact force, (ft.), TL-3 Conditions

$$L_c := \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2}\right)^2 + H \cdot \left(\frac{M_b + M_w \cdot H}{M_c}\right)} \quad \text{(Equation A13.3.1-2, pg. A13-6)}$$

$$L_c = 3.95 \text{ ft}$$

$$R_w := \left(\frac{2}{2 \cdot L_c - L_t}\right) \left(M_b + M_w \cdot H + \frac{M_c \cdot L_c^2}{H}\right) \quad \text{(Equation A13.3.1-1, pg. A13-6)}$$

$$R_w = 41.46 \text{ kips} \quad \text{Total Transverse Resistance of Rail, (Kips)}$$

$$R_w = 41.46 \text{ kips}$$

SUBJECT Florida Bridge Rail Analysis

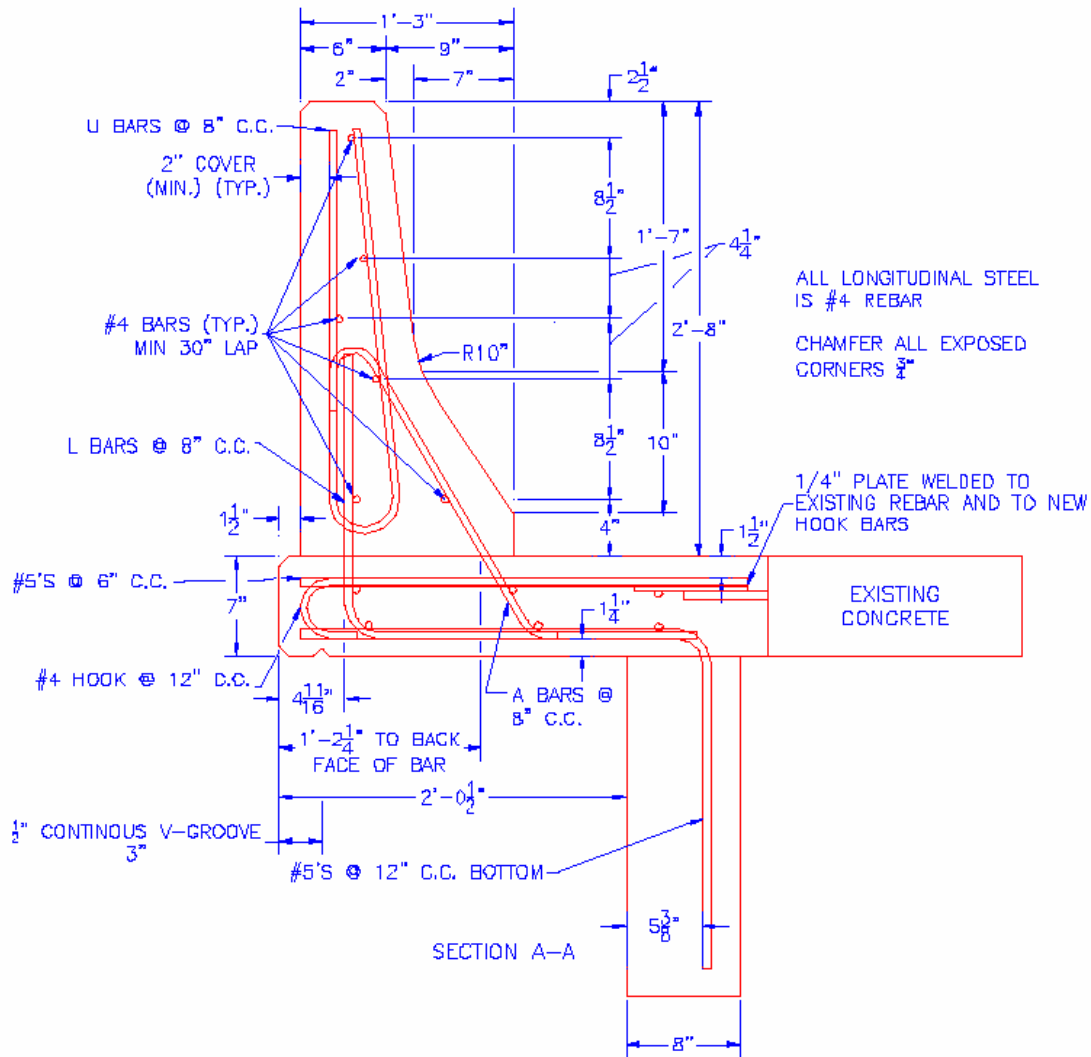
BY: W. Williams

Impact Within Wall Segment

CKD: _____

CLIENT FLADOT

1.) Given Information: 1.) Florida DOT Barrier Details as shown:





PAGE 2 of 6

JOB NO. 421323

Date: 02-17-03

SUBJECT Florida Bridge Rail Analysis
Impact Within Wall Segment
CLIENT FLADOT

BY: W. Williams

CKD: _____

2.) Design Information & Material Properties:

$TL_{3load} := 54\text{kips}$

$f'_c := 4100\text{psi}$ Compressive strength of concrete

$f_y := 60\text{ksi}$ Yield Strength of Reinforcing Steel

$L_t := 3.5\text{ft}$

$H_w := 19\text{in}$... Height of impacted length above radius

SUBJECT Florida Bridge Rail Analysis
Impact Within Wall Segment
 CLIENT FLADOT

BY: W. Williams
 CKD: _____

3.) Calculate the bending Capacity of the Rail about the Longitudinal Axis: M_c , (K-F/F):

$f_y = 60 \text{ ksi}$ Yield strength of rebar
 $f_c = 4100 \text{ psi}$ Compressive strength of concrete
 $A_{sc} := 0.20 \text{ in}^2 \cdot \frac{12}{8}$ Vertical #4 Bars @ 8" O.C. $A_{sc} = 0.3 \text{ in}^2$
 $b_c := 12 \text{ in}$ Unit width of wall, (in)
 $a_c := \frac{A_{sc} \cdot f_y}{0.85 \cdot f_c \cdot b_c}$ $a_c = 0.43 \text{ in}$

$d_c := \frac{5.75 \text{ in} + 0 \text{ in}}{1}$ "approximate weighted average distance to tension steel from radius to top steel in barrier.

$d_c = 5.75 \text{ in}$

Calculate M_c :

with: $d_c = 5.75 \text{ in}$ $\phi := 1.0$
 $A_{sc} = 0.3 \text{ in}^2$
 $f_y = 60 \text{ ksi}$
 $a_c = 0.43 \text{ in}$

Therefore:

$$M_c := \frac{(\phi \cdot A_{sc} \cdot f_y) \cdot \left(d_c - \frac{a_c}{2} \right)}{\text{ft}}$$
Ratio M_c to include 12" Wall unit length.

$M_c = 8.3 \text{ ft}^{-1} \text{ kips} \cdot \text{ft}$

FLexural Resistance of 12" width specified in Article A13.4.2 (K-FT/FT)

SUBJECT Florida Bridge Rail Analysis
Impact Within Wall Segment
 CLIENT FLADOT

BY: W. Williams
 CKD: _____

4.) Calculate the bending Capacity of the Wall about the Vertical Axis: M_w , (K-F):

$A_{sw} := 0.2 \text{ in}^2 \cdot 3$... 3 Longitudinal Tension Bars in the impacted area.

$f_y = 60 \text{ ksi}$

$H_w = 19 \text{ in}$

$b_c = 1 \text{ ft}$

$a_w := \frac{A_{sw} \cdot f_y}{0.85 \cdot f_c \cdot b_c}$

$f_c = 4.1 \times 10^3 \text{ psi}$

$a_w = 0.86 \text{ in}$

$d_w := 3 \text{ in} + \frac{9}{16} \text{ in}$..distance to longitudinal tension steel in curb

$d_w = 3.56 \text{ in}$

Calculate M_w :

with:

$d_w = 3.56 \text{ in}$

$H_w = 1.58 \text{ ft}$

$A_{sw} = 0.6 \text{ in}^2$

$\phi = 1$

$f_y = 60 \text{ ksi}$

$a_w = 0.86 \text{ in}$

Therefore:

$$M_w := \frac{\left[\phi \cdot A_{sw} \cdot f_y \cdot \left(d_w - \frac{a_w}{2} \right) \right]}{H_w}$$

$M_w = 5.93 \text{ ft}^{-1} \text{ kips} \cdot \text{ft}$

Flexural Resistance of Wall
in (K-FT/FT)

SUBJECT Florida Bridge Rail Analysis
Impact Within Wall Segment
 CLIENT FLADOT

BY: W. Williams
 CKD: _____

5.) Additional Flexural Ristance from Beam Action in top of Rail: M_b , (K-F):

$$A_{sw} := 0.0 \text{ in}^2 \cdot 2 \quad \dots \text{ No additional beam action provided!}$$

$$f_y = 60 \text{ ksi}$$

$$a_w := \frac{A_{sw} \cdot f_y}{0.85 \cdot f_c \cdot b_c}$$

$$a_w = 0 \text{ in}$$

$$d_w := 19.5 \text{ in} - 2 \text{ in}$$

..distance to longitudinal
tension steel in curb

$$d_w = 17.5 \text{ in}$$

Calculate M_b :

with:

$$d_w = 17.5 \text{ in}$$

$$H_w = 19 \text{ in}$$

$$A_{sw} = 0 \text{ in}^2$$

$$\phi = 1$$

$$f_y = 60 \text{ ksi}$$

$$a_w = 0 \text{ in}$$

Therefore:

$$M_b := \left[\phi \cdot A_{sw} \cdot f_y \cdot \left(d_w - \frac{a_w}{2} \right) \right]$$

$$M_b = 0 \text{ kips} \cdot \text{ft}$$

FLexural Resistance of beam in top of curb
in (K-FT)

SUBJECT Florida Bridge Rail Analysis
Impact Within Wall Segment
 CLIENT FLADOT

BY: W. Williams
 CKD: _____

6.) Determine Ultimate Resistance of Wall at MidSpan:

Calculate L_c ~ Critical length of yield line failure pattern:

with:

$M_b = 0 \text{ kips} \cdot \text{ft}$... No additional beam action resistance

$M_c = 8.3 \frac{\text{kips} \cdot \text{ft}}{\text{ft}}$ Calculated Wall Strengths

$M_w = 5.93 \frac{\text{kips} \cdot \text{ft}}{\text{ft}}$

$H := H_w$

$H = 19 \text{ in}$... Height of rail, (ft.)

Longitudinal length of distribution of impact force, (ft.), TL-3 Conditions

$$L_c := \frac{L_t}{2} + \sqrt{\left(\frac{L_t}{2}\right)^2 + \left[\frac{8 \cdot H \cdot (M_b + M_w \cdot H)}{M_c}\right]}$$
 (Equation A13.3.1-2, pg. A13-6)

$L_c = 5.92 \text{ ft}$

$$R_w := \left(\frac{2}{2 \cdot L_c - L_t}\right) \left(8 \cdot M_b + 8M_w \cdot H + \frac{M_c \cdot L_c^2}{H}\right)$$
 (Equation A13.3.1-1, pg. A13-6)

$R_w = 62.09 \text{ kips}$

Total Transverse Resistance of Rail, (Kips)

$R_w = 62.09 \text{ kips}$

APPENDIX B. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash tests 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 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 (IRIG), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals, from the test vehicle, are recorded before the test and immediately afterwards. A crystal-controlled time reference signal is simultaneously recorded with the data. Wooden dowels actuate pressure-sensitive switches on the bumper of the impacting vehicle prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces an “event” mark on the data record to establish the instant of contact with the installation.

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

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

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartiment impact velocities, time of occupant/compartiment impact after vehicle impact, and the highest 10-millisecond (ms) average ridedown acceleration. WinDigit calculates change in vehicle velocity at the end of a given impulse period. In addition, WinDigit computes maximum average accelerations over 50-ms intervals in each of the three directions. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

Use of a dummy in the 4405-lb (2000 kg) and 17, 621-lb (8000 kg) vehicles is optional according to *NCHRP Report 350*, and there was no dummy used in the tests with the 2000P vehicle.

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field-of-view parallel to and aligned with the installation at the downstream end. A flash bulb activated by pressure-sensitive tape switches was positioned on the impacting vehicle to indicate the instant of contact with the installation and was visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain time-event, displacement, and angular data. A 16-mm movie cine, a BetaCam, a VHS-format video camera and recorder, and still cameras were used to record and document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle was tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable was connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2-to-1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remained free-wheeling, i.e., no steering or

braking inputs, until the vehicle cleared the immediate area of the test site, at which time the vehicle's brakes were activated to bring it to a safe and controlled stop.

APPENDIX C. TEST VEHICLE PROPERTIES AND INFORMATION

Date: 02-18-2003 Test No.: 421323-1 VIN No. 1GDG7D1B86V542599

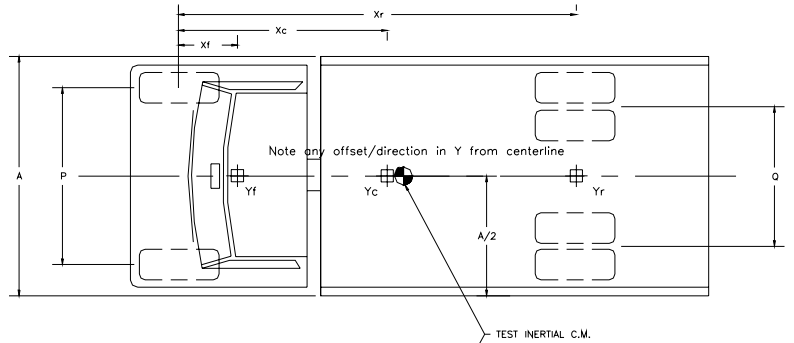
Year: 1986 Make: GMC Model: 7000 Sierra

Tire Inflation Pressure: _____ Odometer: _____ Tire Size: 11 R 22.5

Describe any damage to the vehicle prior to test: _____

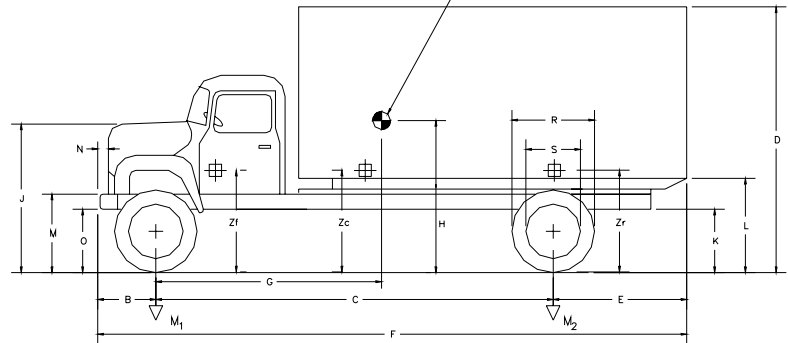
⊕ Denotes accelerometer location.

NOTES: _____



Accelerometer Locations (mm):

	x	y	z
f	1320	300 rt	1145
c	N/A	N/A	N/A
r	4820	0	1130



Geometry (mm)

A	2438	E	2515	J	1588	N	133	R	1016
B	813	F	8128	K	762	O	521	S	591
C	4801	G	3279.3	L	1232	P	2007		
D	3442	H		M	851	Q	1829		

Mass (kg)	Curb	Test Inertial	Gross Static
M ₁	2170	2538	_____
M ₂	2906	5471	_____
M _{Total}	5076	8009	_____

Mass Distribution (kg): LF: 1435 RF: 1103 LR: 2667 RR: 2803

Figure 26. Vehicle Properties for Test 421323-1.

Date: 03-18-2003 Test No.: 421323-2 VIN No. 1GCGC24R9W2186961

Year: 1998 Make: Chevrolet Model: Cheyenne 2500

Tire Inflation Pressure: 50/80psi Odometer: 164603 Tire Size: 245/75 R 16

Describe any damage to the vehicle prior to test: #505

● Denotes accelerometer location.

NOTES: _____

Engine Type: V8

Engine CID: 5.7 Liter

Transmission Type:

Auto

Manual

Optional Equipment:

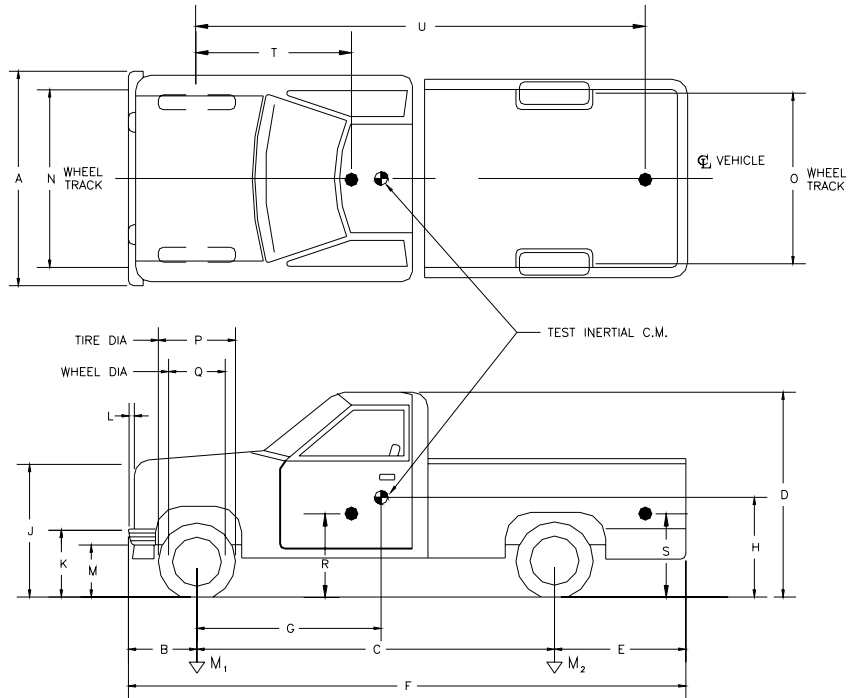
8-lug

Dummy Data:

Type: None

Mass: N/A

Seat Position: N/A



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>1420.86</u>	L	<u>70</u>	P	<u>725</u>	T	<u>1460</u>
D	<u>1820</u>	H	<u> </u>	M	<u>415</u>	Q	<u>440</u>	U	<u>3360</u>

Mass (kg)	<u>Curb</u>	<u>Test Inertial</u>	<u>Gross Static</u>
M ₁	<u>1220</u>	<u>1188</u>	<u> </u>
M ₂	<u>954</u>	<u>875</u>	<u> </u>
M _{Total}	<u>2174</u>	<u>2063</u>	<u> </u>

Mass Distribution (kg): LF: 594 RF: 594 LR: 431 RR: 444

Figure 27. Vehicle Properties for Test 421323-2.

Table 3. Exterior Crush Measurements for Test 421323-2.

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.
 All measurements in mm.

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆	±D
		Width** (CDC)	Max*** Crush								
1	At Front Bumper	740	500	880	500	320	260	130	70	0	-440
2	770 mm Above Ground	740	640	1230	0	130	N/A	N/A	470	640	7610

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).

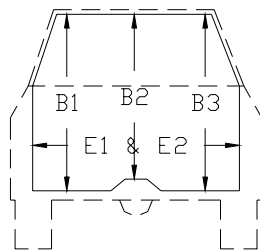
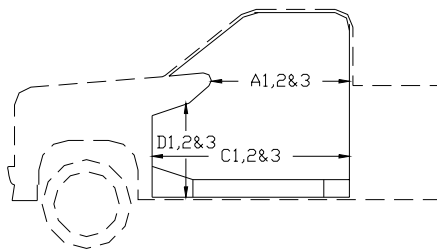
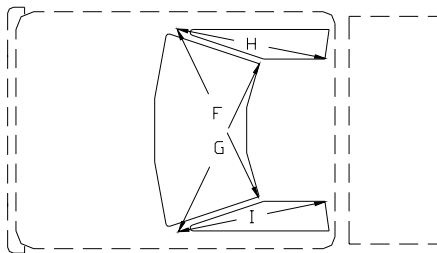
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 4. Occupant Compartment Measurements for Test 421323-2.

TRUCK

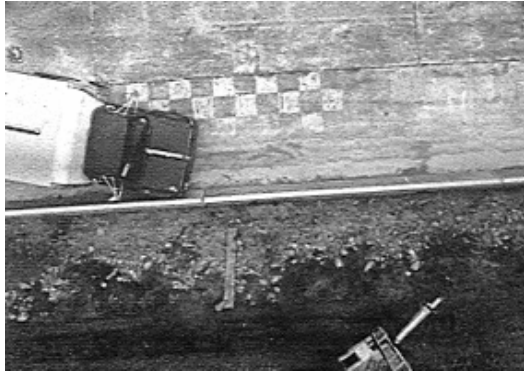
Occupant Compartment Deformation



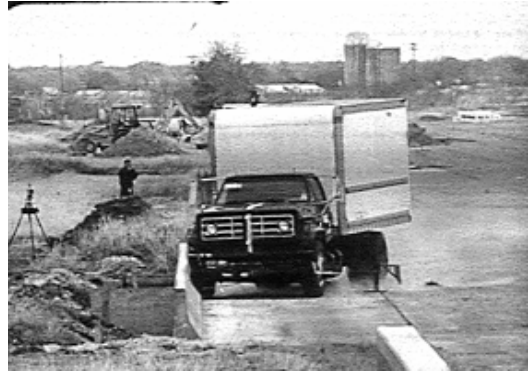
	BEFORE (mm)	AFTER (mm)
A1	868	840
A2	935	928
A3	931	940
B1	1072	1080
B2	1024	940
B3	1076	1076
C1	1372	1285
C2	N/A	N/A
C3	1372	1372
D1	317	276
D2	155	112
D3	308	331
E1	1588	1605
E2	1592	1637
F	1455	1455
G	1455	1465
H	1265	1260
I	1247	1247
J*	1525	1443

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

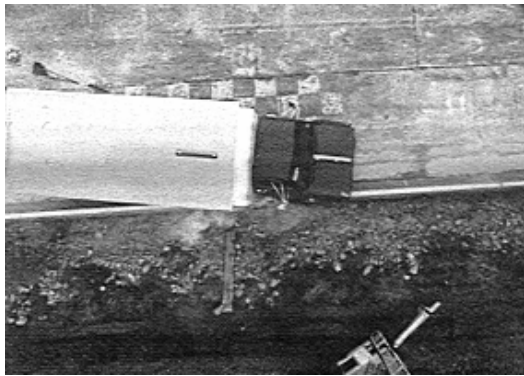
APPENDIX D. SEQUENTIAL PHOTOGRAPHS



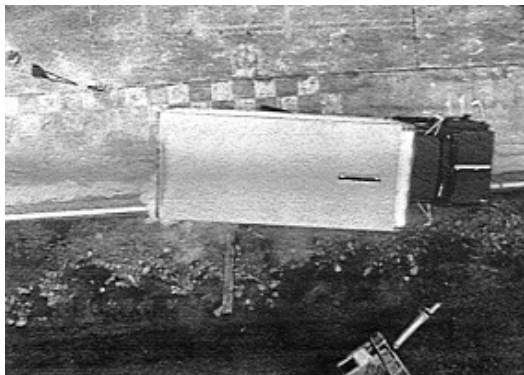
0.000 s



0.097 s



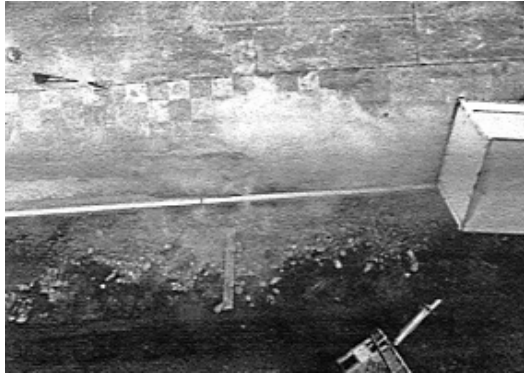
0.194 s



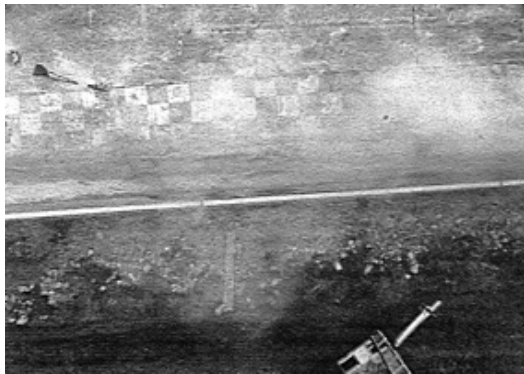
0.364 s



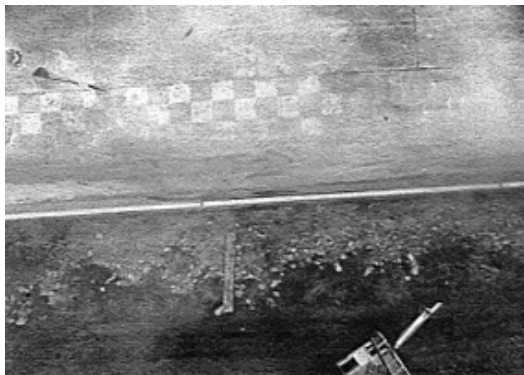
Figure 28. Sequential Photographs for Test 421323-1 (Overhead and Frontal Views).



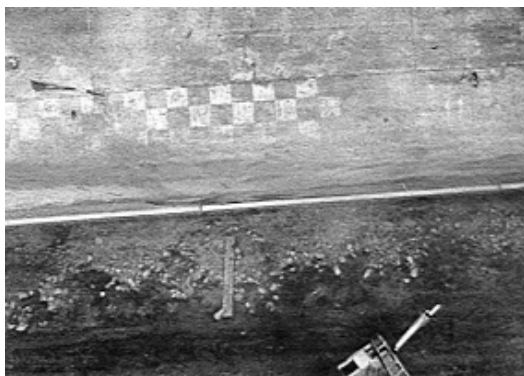
0.728 s



1.457 s



2.428 s



3.885 s

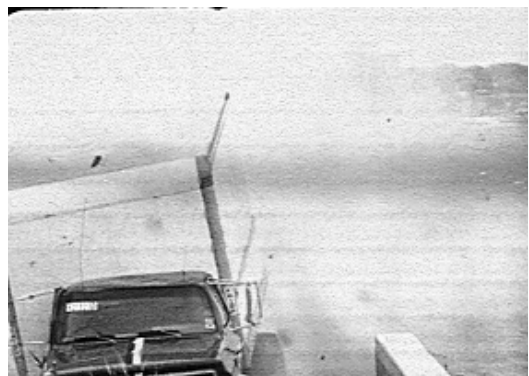
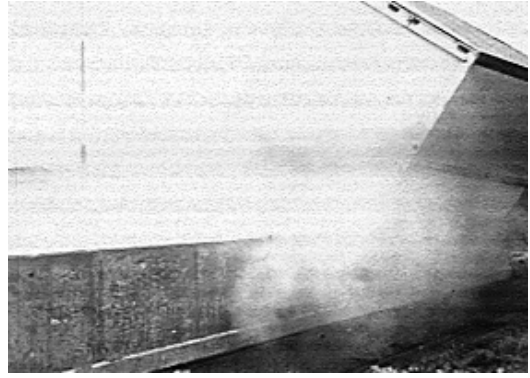


Figure 28. Sequential Photographs for Test 421323-1 (Overhead and Frontal views) (continued).



0.000 s



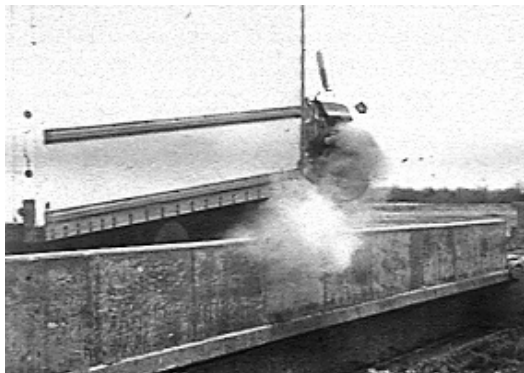
0.728 s



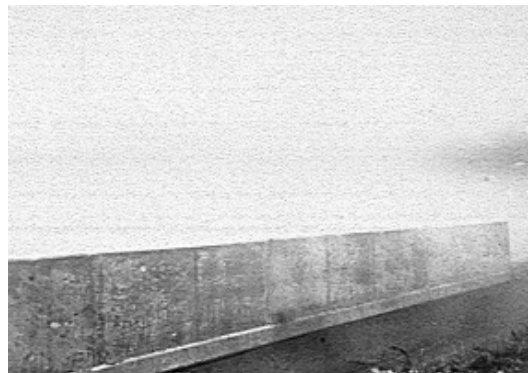
0.097 s



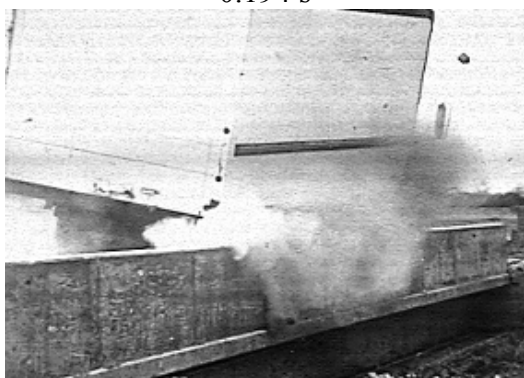
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0.194 s



2.428 s



0.364 s

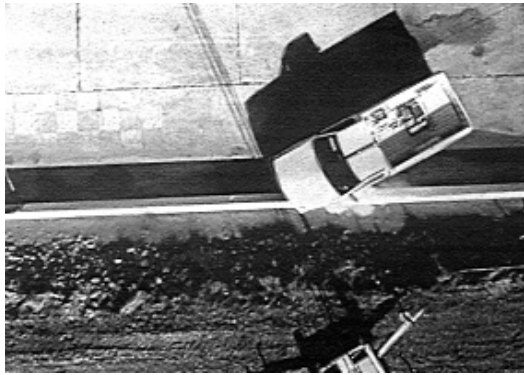


3.885 s

Figure 29. Sequential Photographs for Test 421323-1 (Rear View).



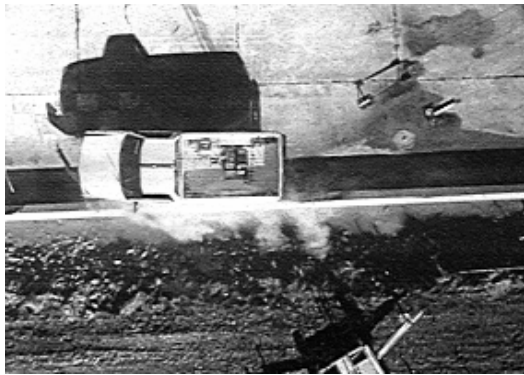
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0.049 s



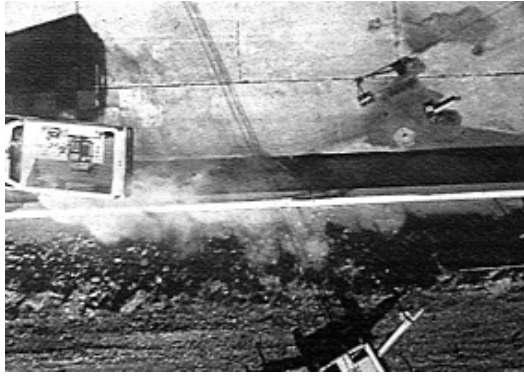
0.146 s



0.292 s



Figure 30. Sequential Photographs for Test 421323-2 (Overhead and Frontal Views).



0.487 s



0.974 s



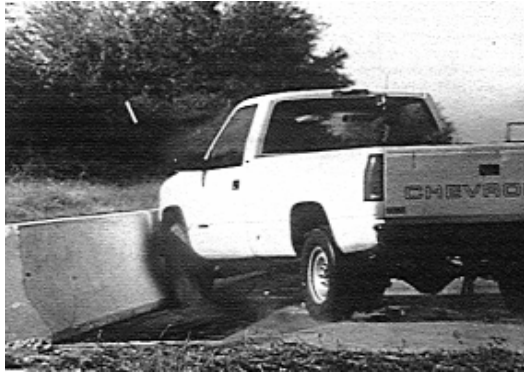
1.461 s



2.192 s



Figure 30. Sequential Photographs for Test 421323-2 (Overhead and Frontal Views) (continued).



0.000 s



0.487 s



0.049 s



0.974 s



0.146 s



1.461 s



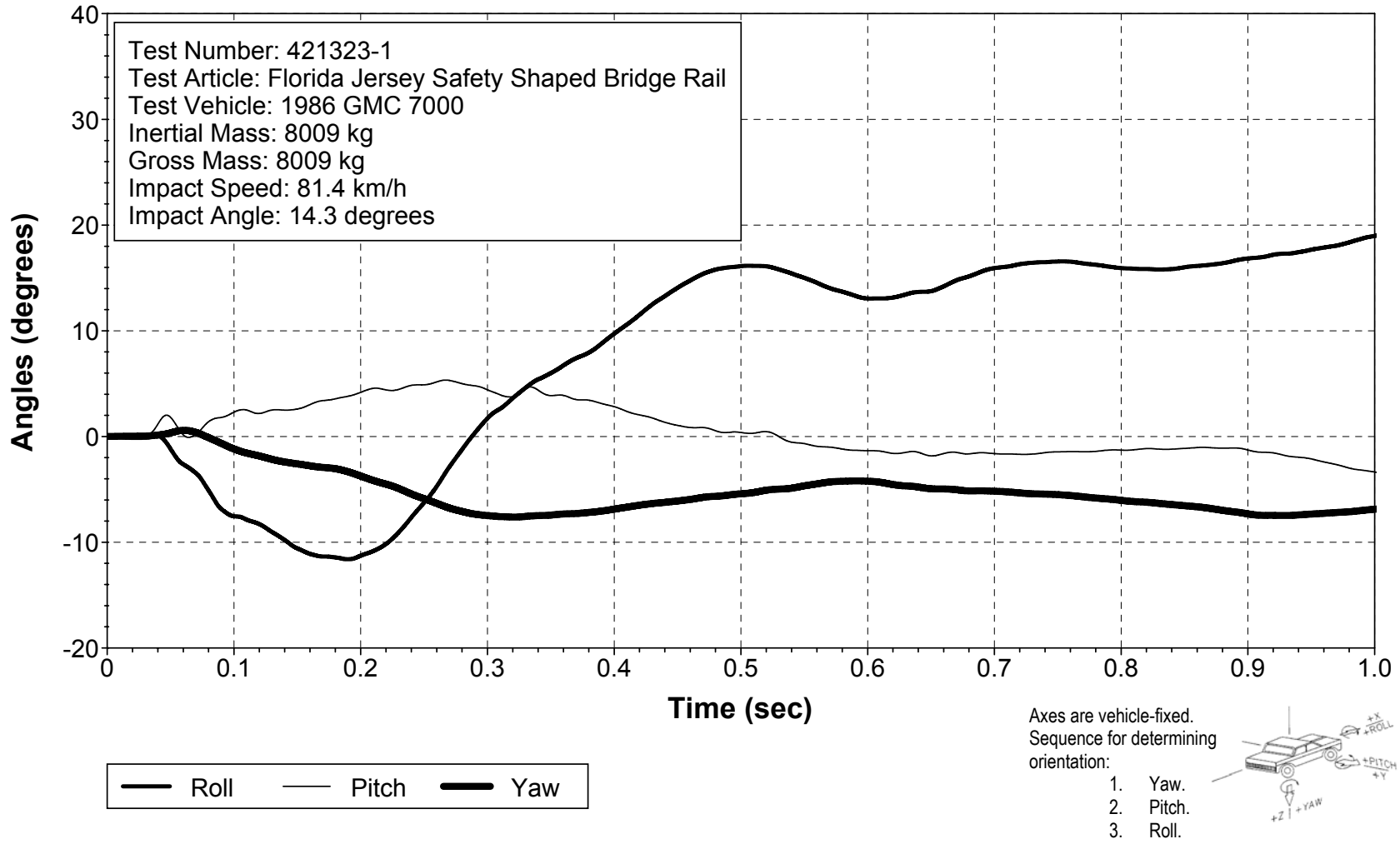
0.292 s



2.192 s

Figure 31. Sequential Photographs for Test 421323-2 (Rear View).

Roll, Pitch and Yaw Angles



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Figure 32. Vehicular Angular Displacements for Test 421323-1.

X Acceleration at CG

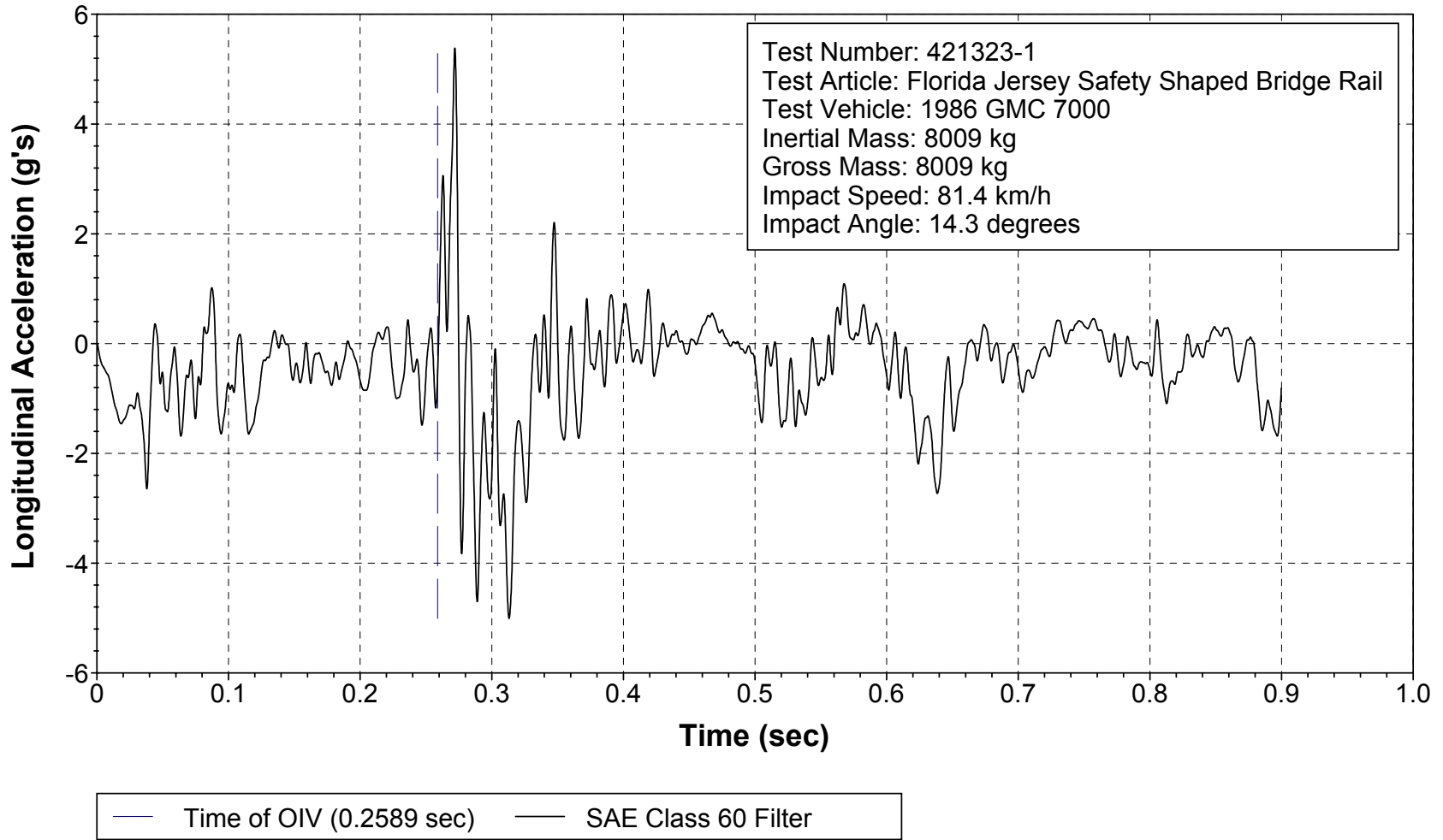


Figure 33. Vehicle Longitudinal Accelerometer Trace for Test 421323-1 (Accelerometer Located at Center of Gravity).

Y Acceleration at CG

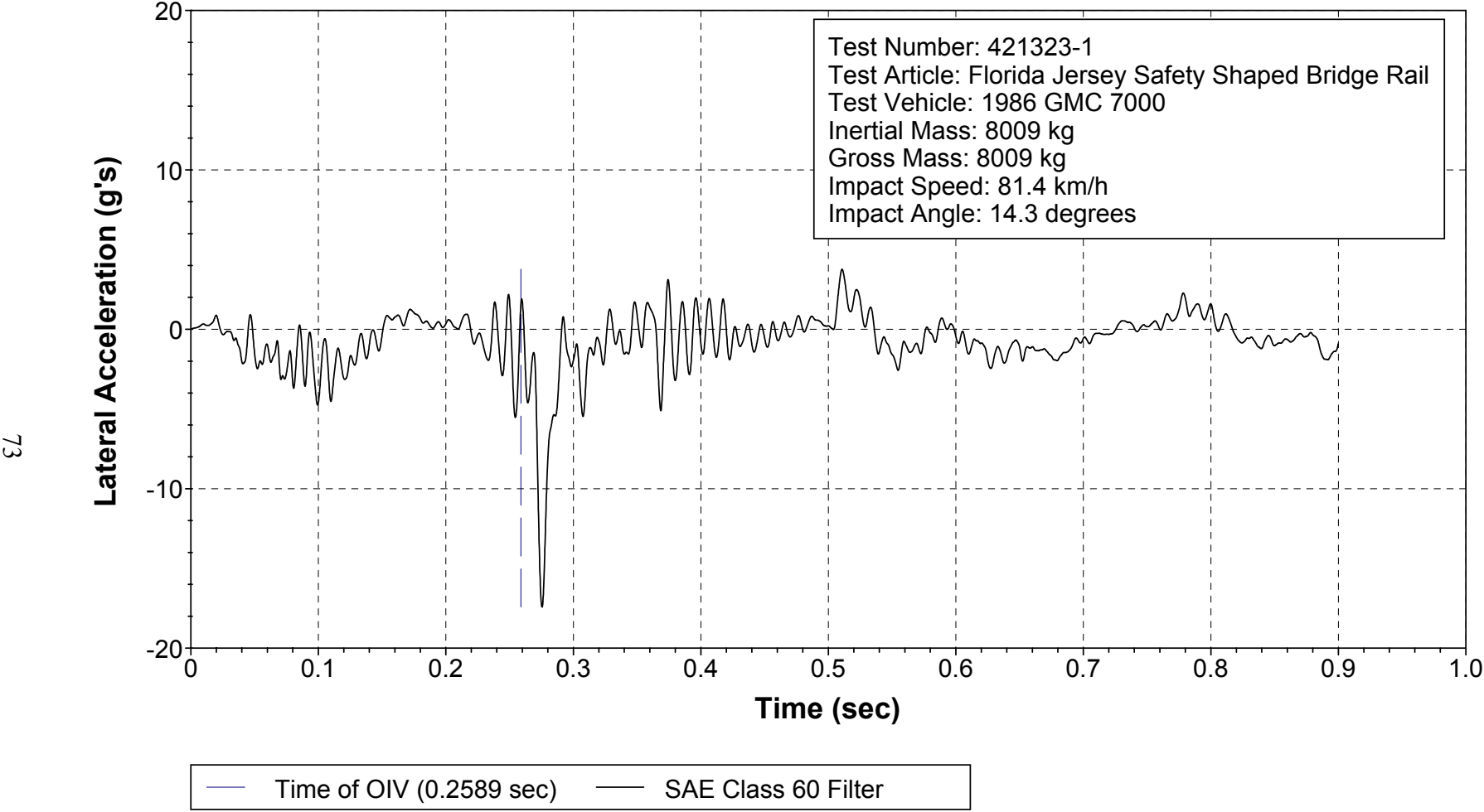


Figure 34. Vehicle Lateral Accelerometer Trace for Test 421323-1 (Accelerometer Located at Center of Gravity).

Z Acceleration at CG

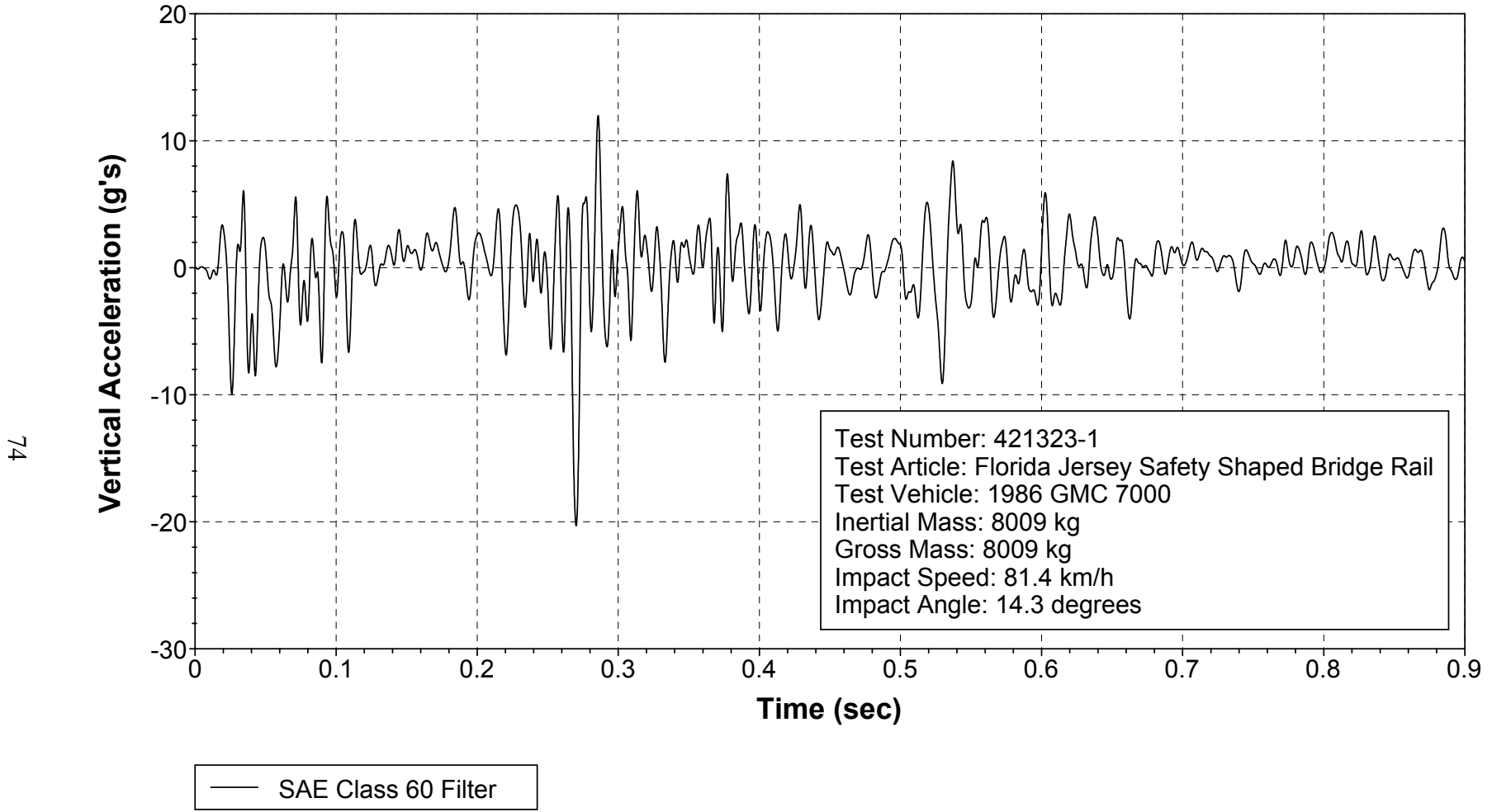
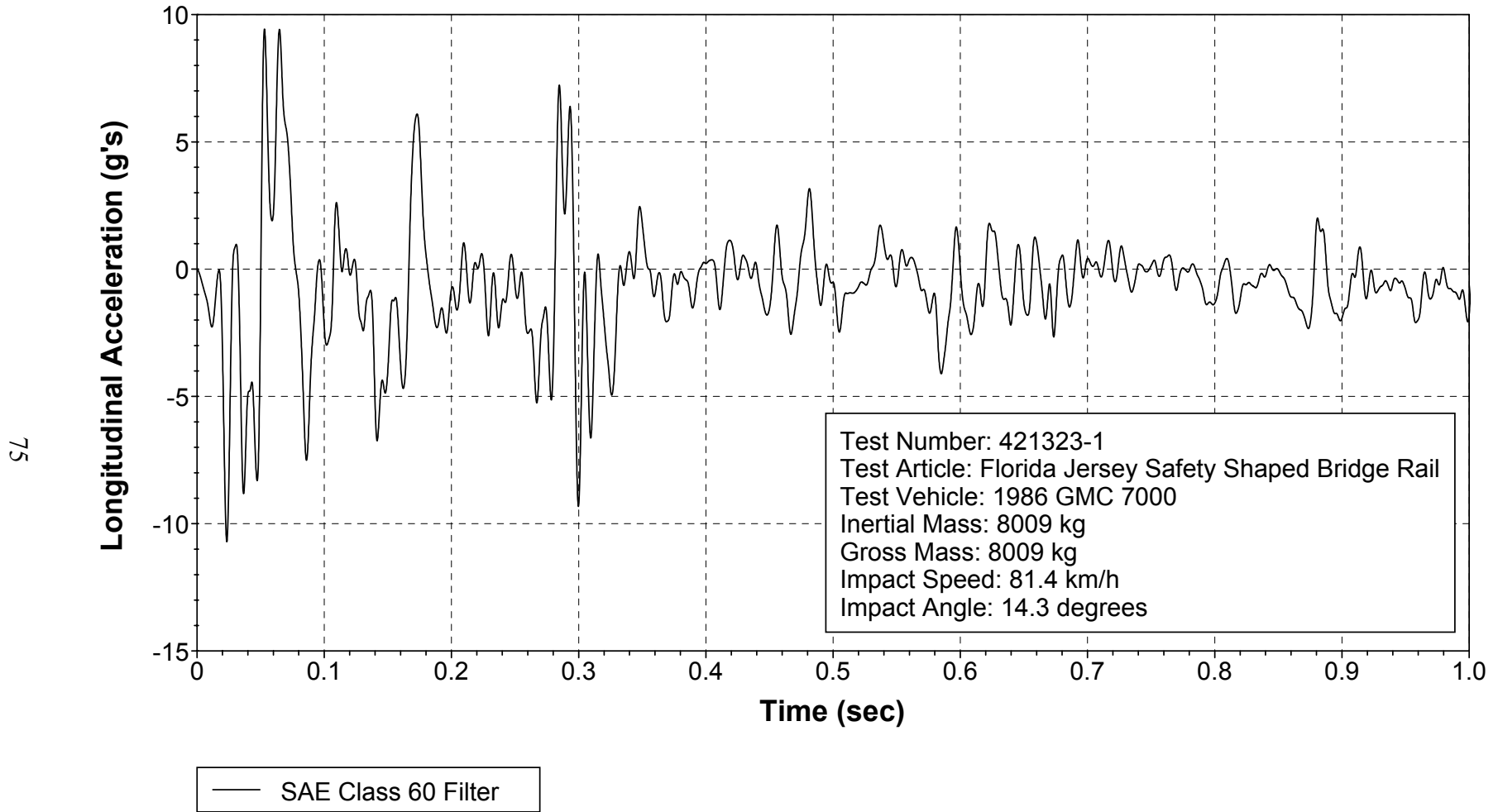


Figure 35. Vehicle Vertical Accelerometer Trace for Test 421323-1 (Accelerometer Located at Center of Gravity).

X Acceleration in Cab



**Figure 36. Vehicle Longitudinal Accelerometer Trace for Test 421323-1
(Accelerometer Located in Cab).**

Y Acceleration in Cab

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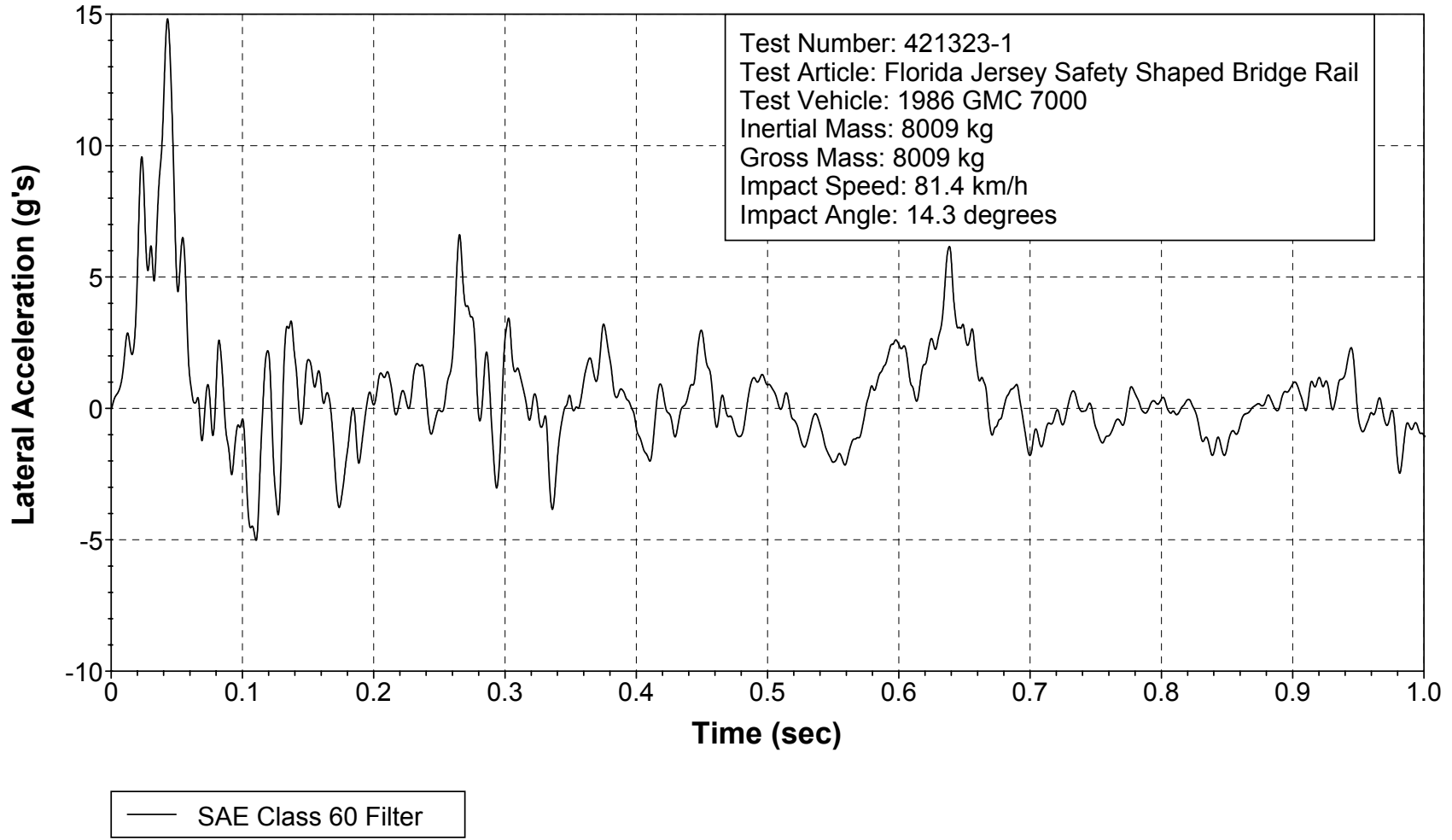


Figure 37. Vehicle Lateral Accelerometer Trace for Test 421323-1 (Accelerometer Located in Cab).

X Acceleration over Rear Axle

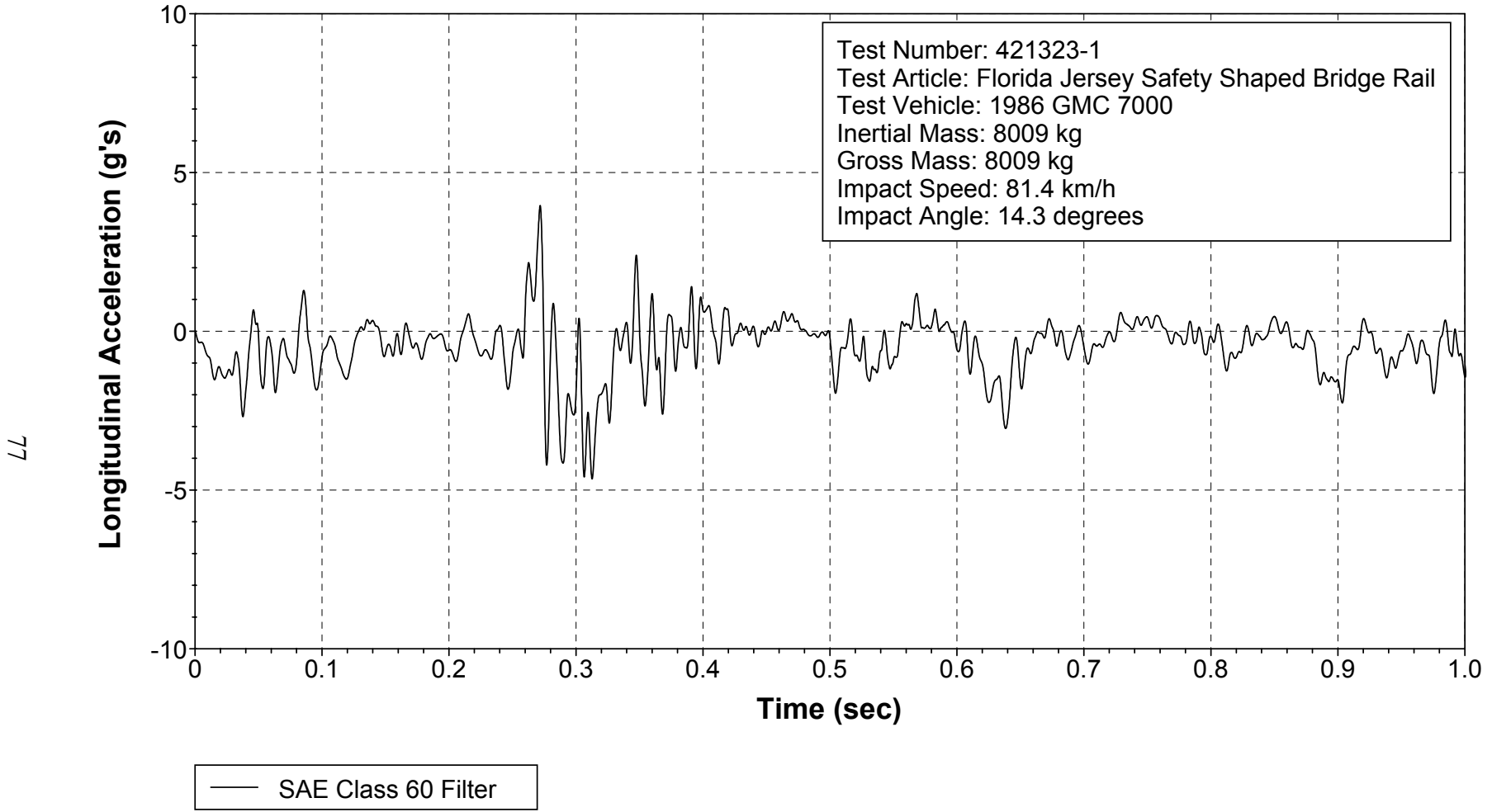


Figure 38. Vehicle Longitudinal Accelerometer Trace for Test 421323-1 (Accelerometer Located over Rear Axle).

Y Acceleration over Rear Axle

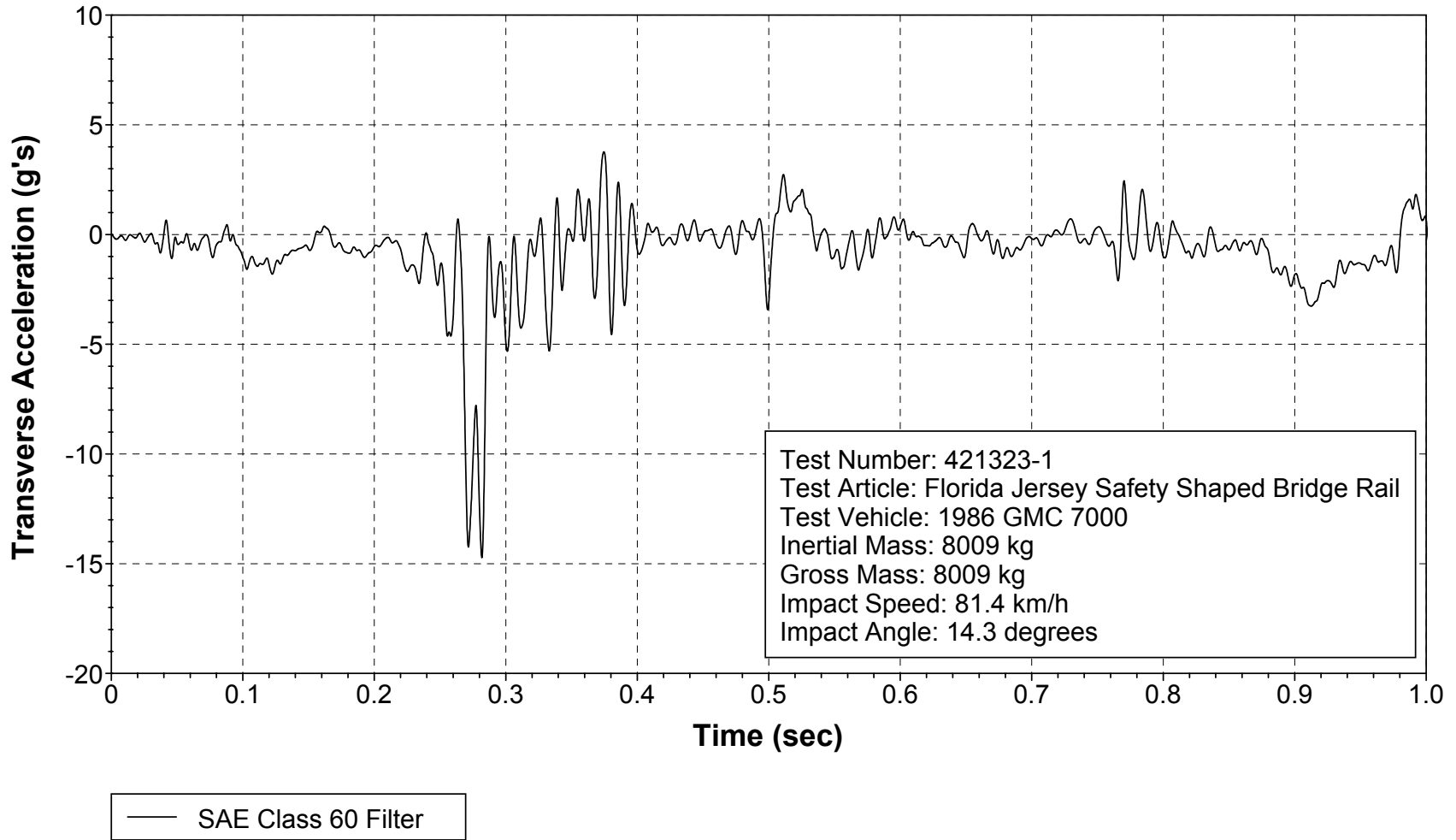
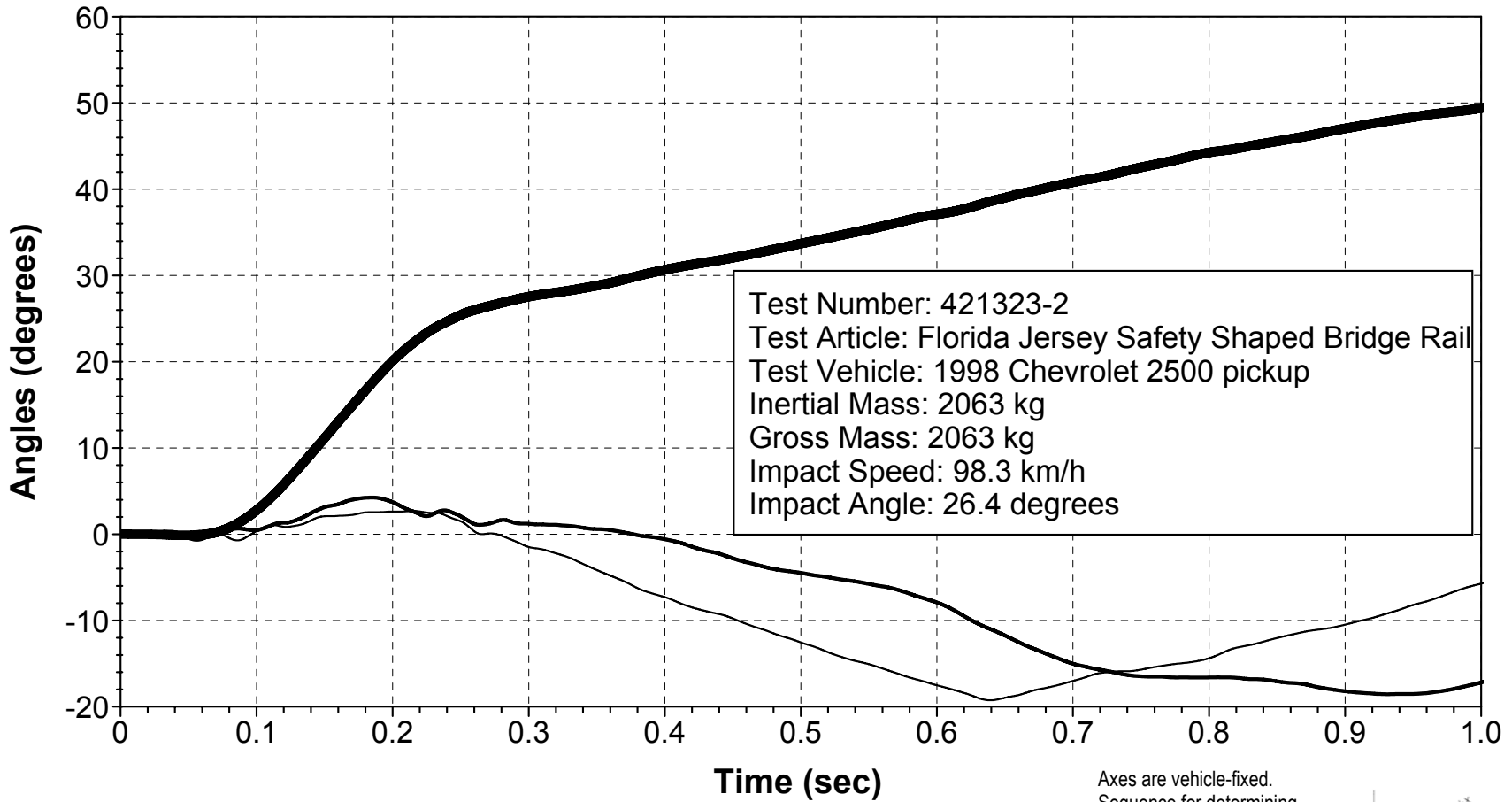


Figure 39. Vehicle Lateral Accelerometer Trace for Test 421323-1 (Accelerometer Located over Rear Axle).

Roll, Pitch and Yaw Angles

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Test Number: 421323-2
 Test Article: Florida Jersey Safety Shaped Bridge Rail
 Test Vehicle: 1998 Chevrolet 2500 pickup
 Inertial Mass: 2063 kg
 Gross Mass: 2063 kg
 Impact Speed: 98.3 km/h
 Impact Angle: 26.4 degrees

— Roll — Pitch — Yaw

Axes are vehicle-fixed.
 Sequence for determining orientation:

4. Yaw.
5. Pitch.
6. Roll.

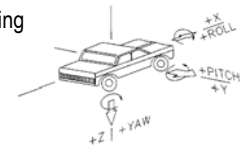


Figure 40. Vehicular Angular Displacements for Test 421323-2.

X Acceleration at CG

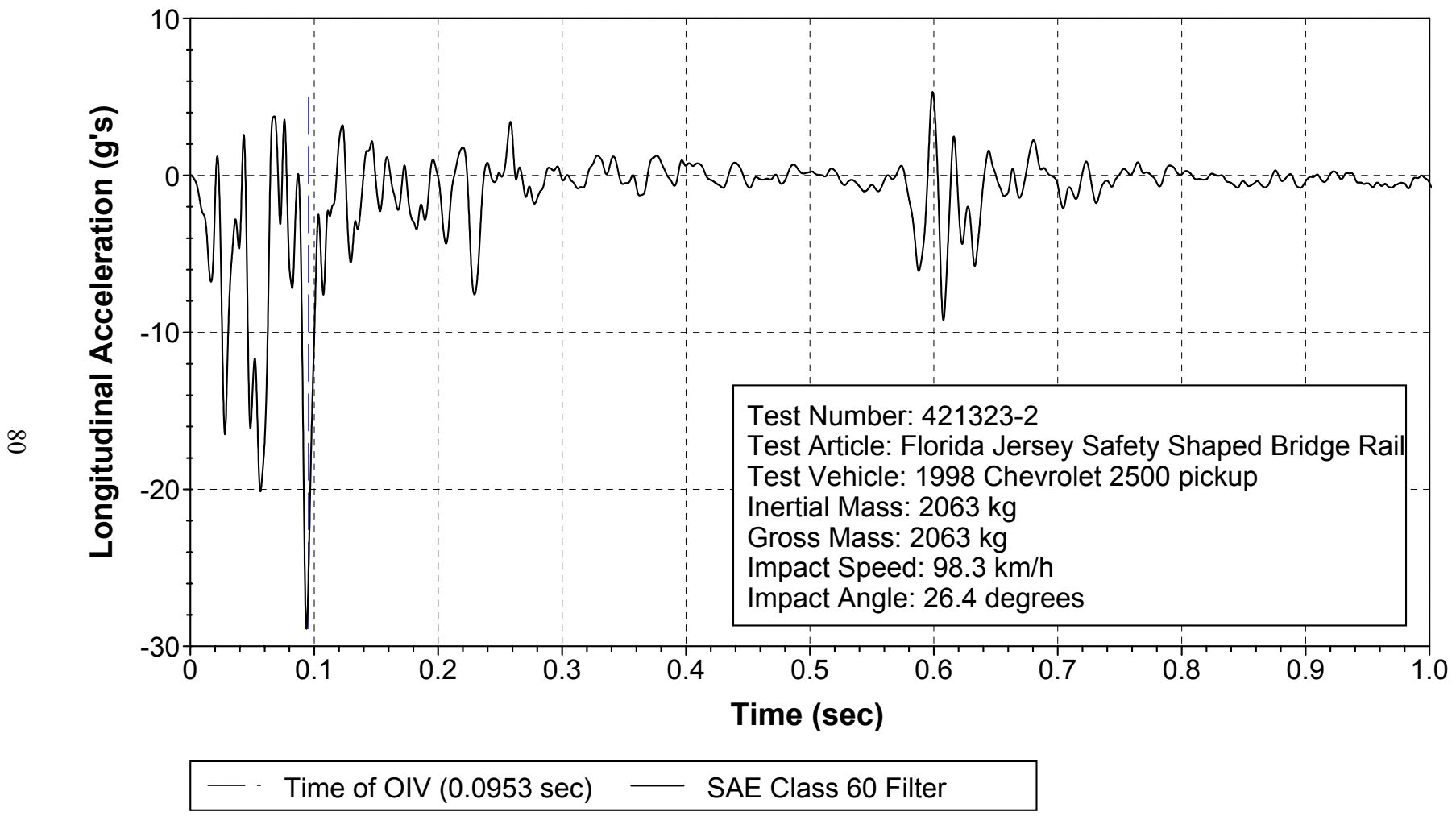


Figure 41. Vehicle Longitudinal Accelerometer Trace for Test 421323-2 (Accelerometer Located at Center of Gravity).

Y Acceleration at CG

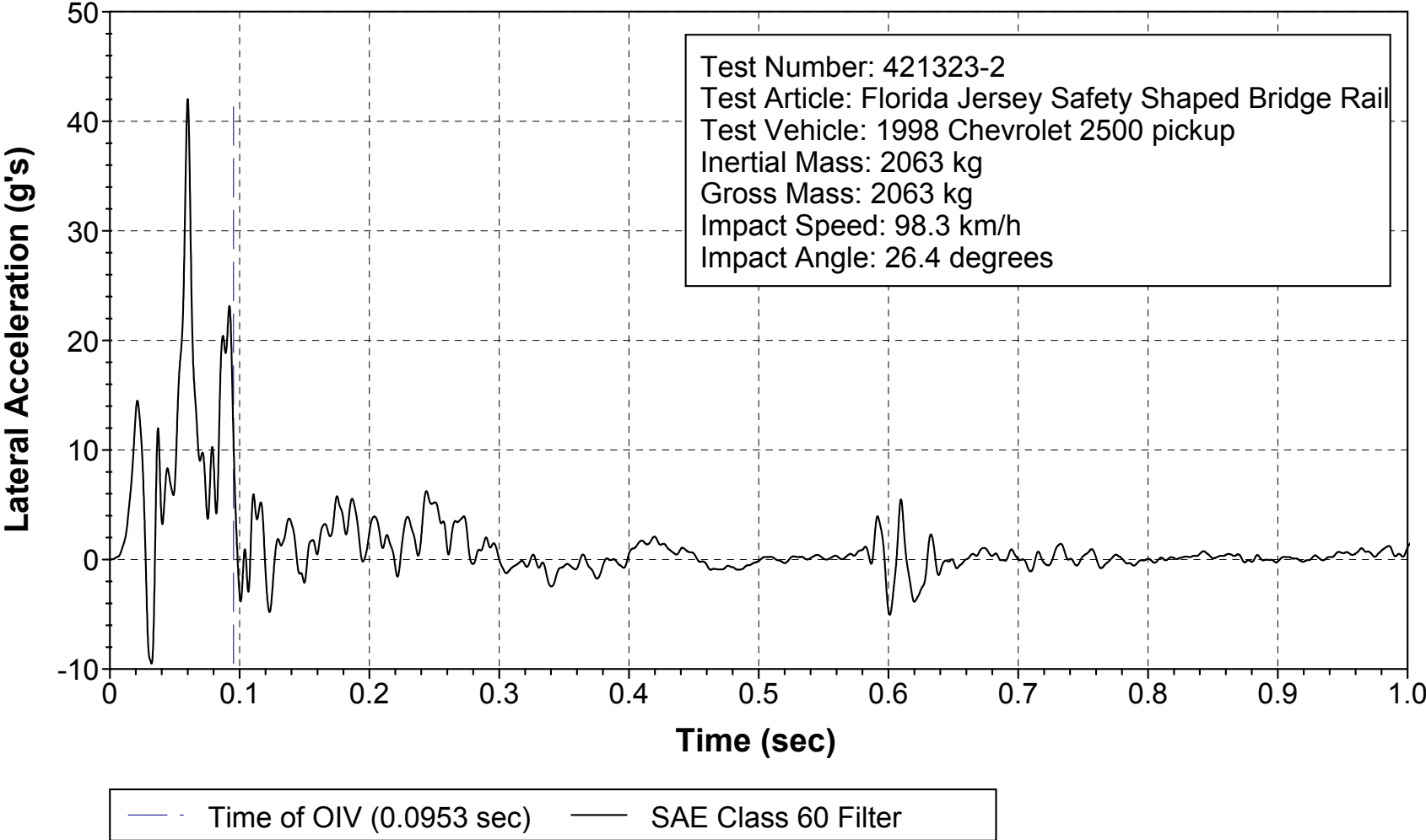


Figure 42. Vehicle Lateral Accelerometer Trace for Test 421323-2 (Accelerometer Located at Center of Gravity).

Z Acceleration at CG

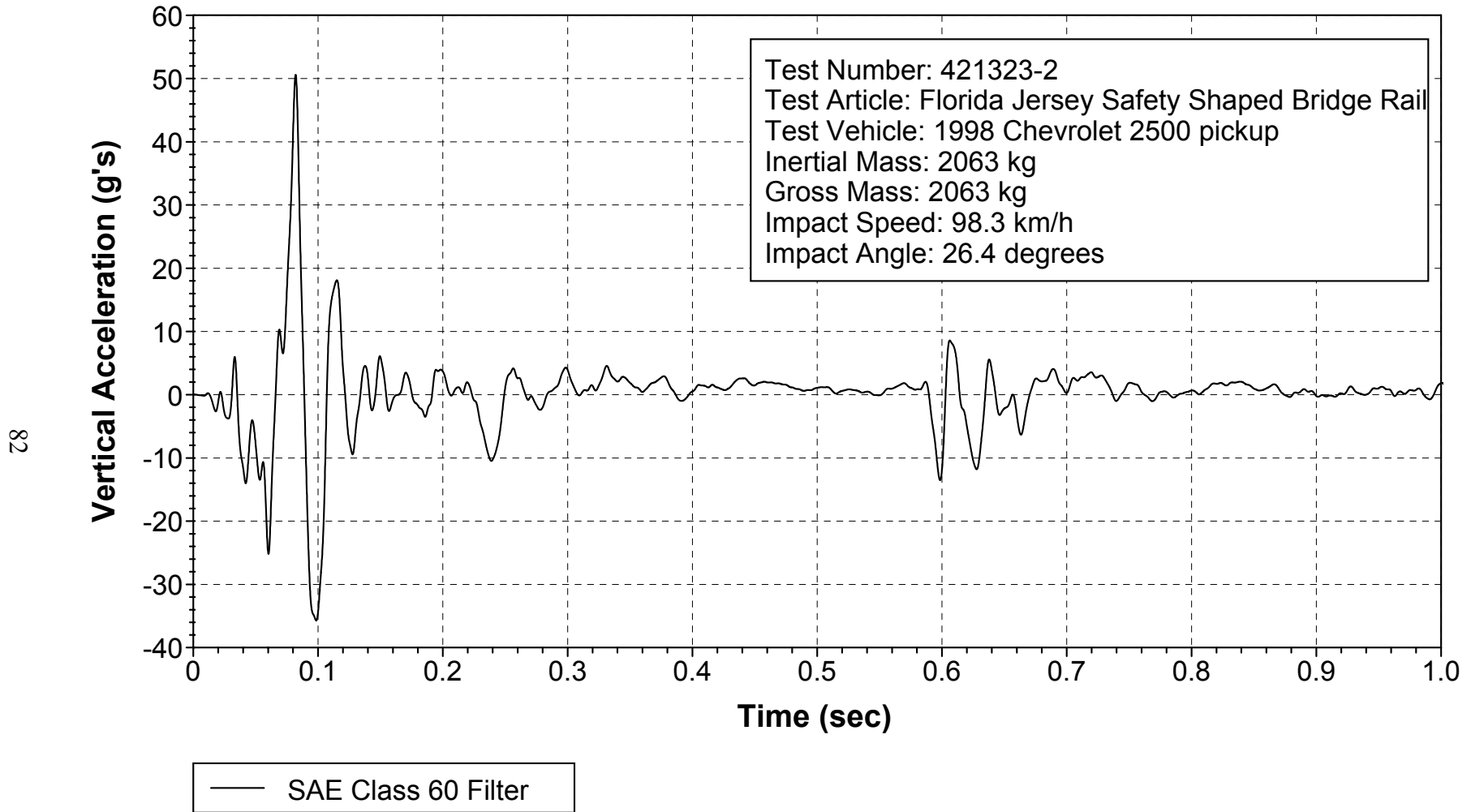
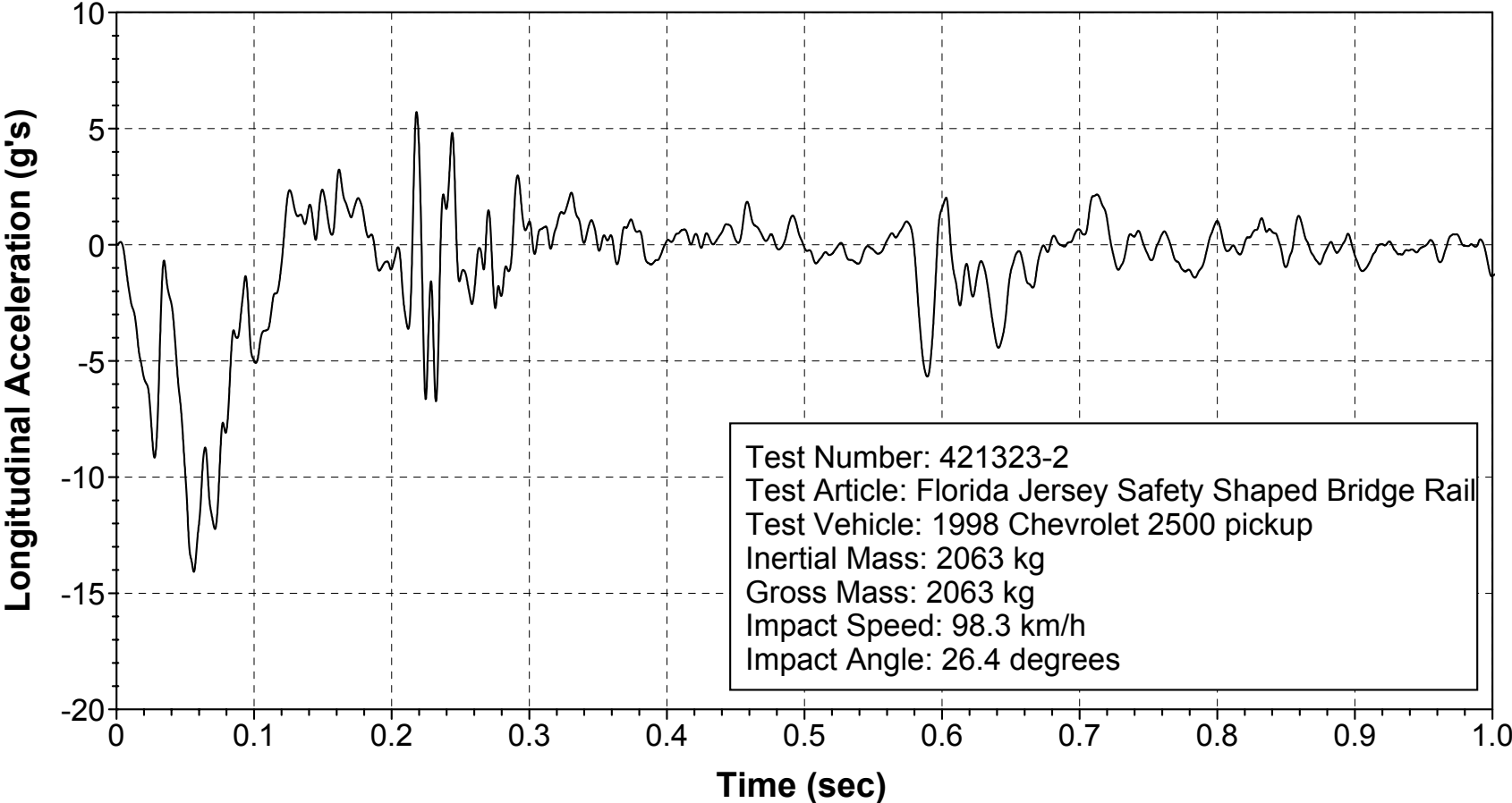


Figure 43. Vehicle Vertical Accelerometer Trace for Test 421323-2
(Accelerometer Located at Center of Gravity).

X Acceleration over Rear Axle



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— SAE Class 60 Filter

Figure 44. Vehicle Longitudinal Accelerometer Trace for Test 421323-2 (Accelerometer Located over Rear Axle).

Y Acceleration over Rear Axle

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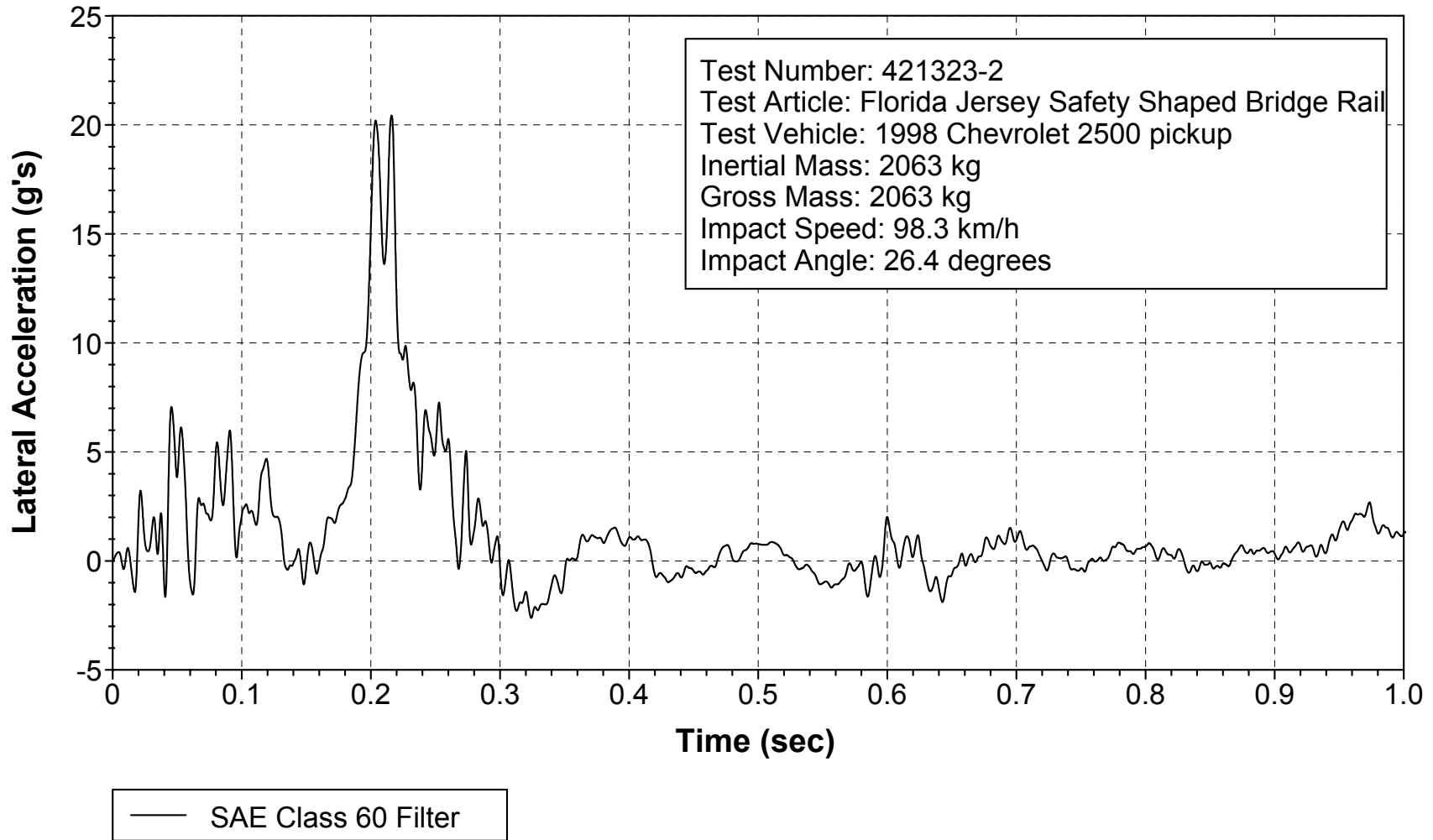


Figure 45. Vehicle Lateral Accelerometer Trace for Test 421323-2
(Accelerometer Located over Rear Axle).

Z Acceleration over Rear Axle

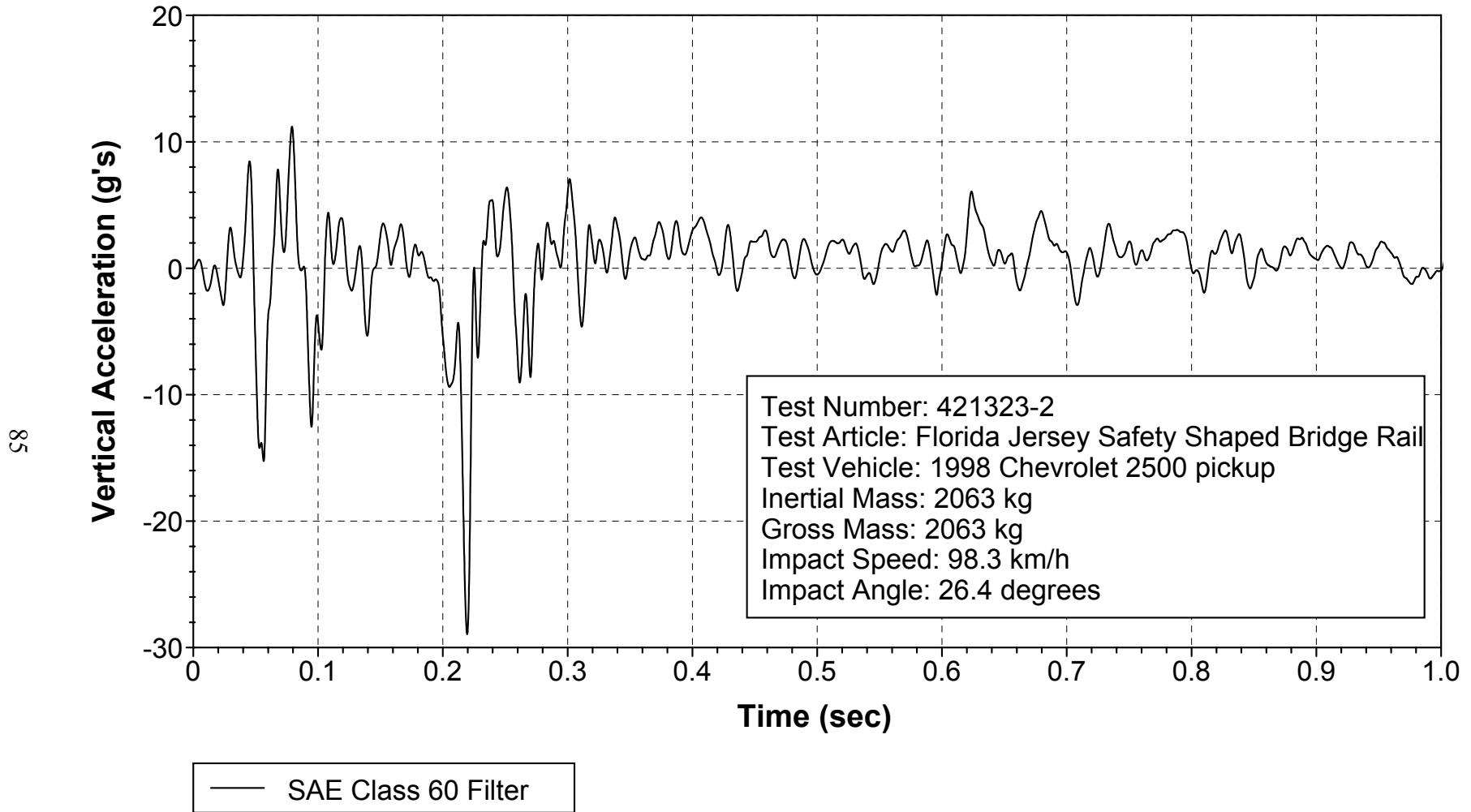


Figure 46. Vehicle Vertical Accelerometer Trace for Test 421323-2 (Accelerometer Located over Rear Axle).

