NCHRP REPORT 350 TEST 4-11 OF THE TACOMA NARROWS BRIDGE RAIL

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KEY WORDS

Bridge Rail, Longitudinal Barriers, Crash Testing, Roadside Safety Features

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16. Abstract

Texas Transportation Institute (TTI) evaluated the “two tube Illinois Rail 2399-1” anchored to the Tacoma Narrows Bridge in accordance with an anchorage design per American Association of State Highways and Transportation Officials (AASHTO) Specifications as provided by Parsons Transportation Group/ Howard Needles Tammen & Bergendoff (PTG/HNTB). This analysis included the analysis and applicability of previous crash testing and approvals, and performing a full-scale crash test according to pre-determined crash test matrix sequences and *National Cooperative Highway Research Program* (*NCHRP) Report 350* guidelines.

This report presents the details of the test installation, detailed description of the full-scale crash test, and the results and evaluation of the crash test as per *NCHRP Report 350* test 4-11.

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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 yards	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)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celsius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

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

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

(Revised September 1993)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

PROBLEM

A major rehabilitation of the Tacoma Narrows Bridge is being performed. As part of the project, the Washington State Department of Transportation required the contractor provide a bridge rail that meets Test Level 4 (TL-4) of *NCHRP (National Cooperative Highway Research Program) Report 350, "Recommended Procedures for the Safety Performance Evaluation of Highway Features."*[1] A TL-4 bridge rail will contain and redirect an 8000 kg single unit box truck impacting the system at 15 degrees and 80 km/h, an 820C impacting at 20 degrees and 100 km/h, as well as a 2000 kg pickup truck impacting at 25 degrees and 100 km/h.

BACKGROUND

The Illinois 2399-1 Bridge Rail was tested under contract DTFH61-86-C-00071 in both a surface mounted and side mounted configuration.[2,3] Two rectangular tubular members were attached to W6x25 posts spaced at 6 ft 3 in (1.9 m). The surface mounted version was atop a 7 in (178 mm) curb and through bolted to the deck. The side-mounted version was anchored into a 10 in (250 mm) thick deck. Both versions were successfully tested to Test Level 4 (TL-4) conditions.

OBJECTIVES/SCOPE OF RESEARCH

Texas Transportation Institute (TTI) evaluated the "two tube Illinois Rail 2399-1" anchored to the Tacoma Narrows Bridge in accordance with an anchorage design per American Association of State Highways and Transportation Officials (AASHTO) Specifications as provided by Parsons Transportation Group/ Howard Needles Tammen & Bergendoff (PTG/HNTB). This evaluation included the analysis and applicability of previous crash testing and approvals, and performance of a full-scale crash test according to *NCHRP Report 350* guidelines.

The test matrix for TL-4 includes tests 4-10; an 820 kg small passenger car impacting the system at 20 degrees and 100 km/h, 4-11; a 2000 kg pickup truck impacting the system at 25 degrees and 100 km/h, and 4-12; an 8000 kg single unit truck with box impacting the system at 15 degrees and 80 km/h. The design to be tested and evaluated for PTG/HNTB was similar to the previously tested Illinois two tube rail except the post spacing was increased to a maximum of 7 ft 9 in compared to the 6 ft 3 in used in the Illinois design. Deeper W8x24 posts and polymer offset blocks were incorporated into the new design in anticipation of slightly higher post loads and deflections.

In conversations with Washington State DOT (WSDOT) and Federal Highway Administration (FHWA), the 2000 kg pickup was determined to be the most critical test with regard to impact force and the potential for vehicular snagging. If acceptable performance was verified in test 4-11, the other tests, 4-10 and 4-12, could possibly be waived.

This report presents the details of the test installation, detailed description of the full-scale crash test, and the results and evaluation of the crash test as per *NCHRP Report 350* test 4-11.

TECHNICAL DISCUSSION

TEST PARAMETERS

Test Facility

The test facilities at the Texas Transportation Institute's Proving Ground consist of an 809-hectare complex of research and training facilities situated 16 km northwest of the main campus of Texas A&M University. The site, formerly an Air Force base, has large expanses of concrete runways and parking aprons well suited for experimental research and testing in the areas of vehicle performance and handling, vehicle-roadway interaction, durability and efficacy of highway pavements, and safety evaluation of roadside safety hardware. The site selected for placing of the Tacoma Narrows Bridge Rail is along a wide out-of-service runway apron. The runway apron consists of an unreinforced jointed concrete pavement in 12.5 ft by 15 ft (3.8 m by 4.6 m) blocks nominally 8-12 in (203-305 mm) deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level.

Test Article – Design and Construction

As discussed previously, the system to be tested under this contract is similar to the Illinois 2399 two tube bridge rail. For retrofit purposes, the post spacings varied from 7 ft 5 in (2.26 m) to 7 ft 9 in (2.36 m) for attachment to existing channel diaphragms. This maximum post spacing exceeds the previously tested post spacing by 18 in (457 mm). The posts were changed to W8x24 from the originally tested W6x25. Portions of the lower flanges were removed for attachment to the channel diaphragms. The top tubular member is a TS 8 x 4x 5/16 and the top of the rail is 2 ft 8 in (813 mm) from the bridge deck. The lower tubular member mounted at 13 in (330 mm) is a TS 6x4x1/4. Both rails were offset from the posts with 4 in (100 mm) deep polyethylene blocks. To further simulate the actual installation, C12x20.7 channels were rigidly attached to concrete stem walls simulating large stringers. In addition, a grate and sidewalk were constructed in the deck as shown in the plan details. Detailed drawings of the installation can be found in figure 1 and photographs of the completed installation are shown in figure 2.

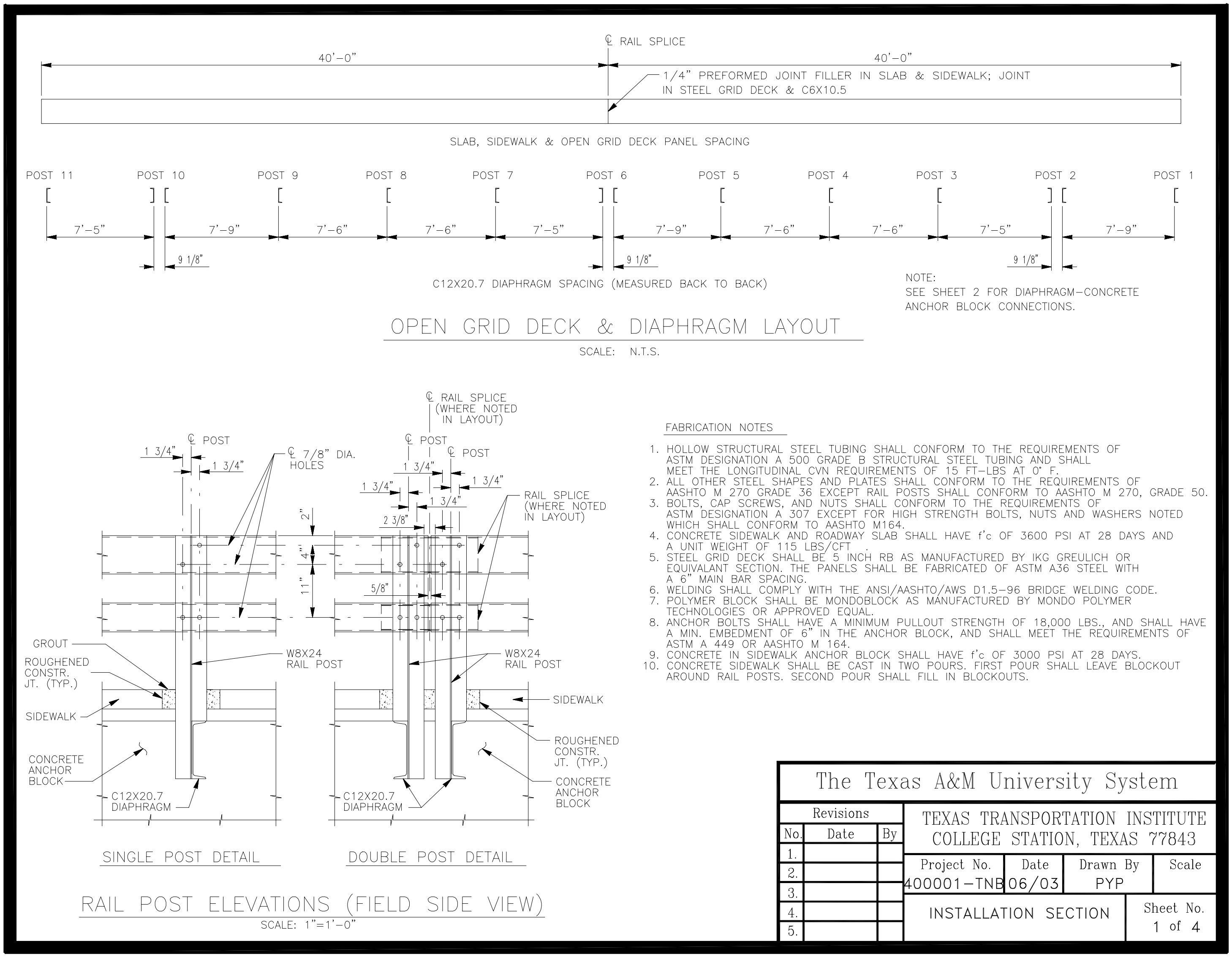


Figure 1. Details of the Tacoma Narrows Bridge Rail.

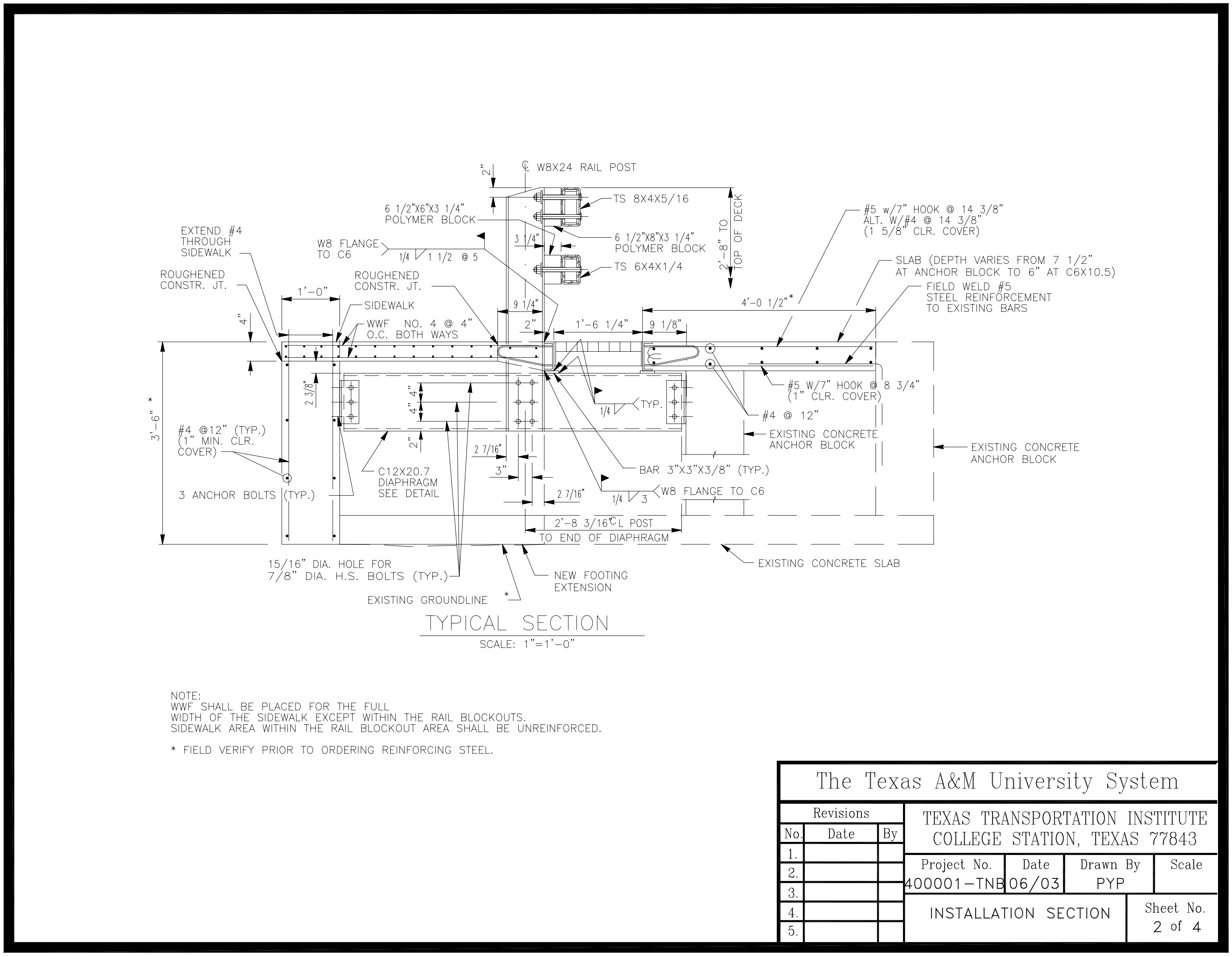


Figure 1. Details of the Tacoma Narrows Bridge Rail (continued).

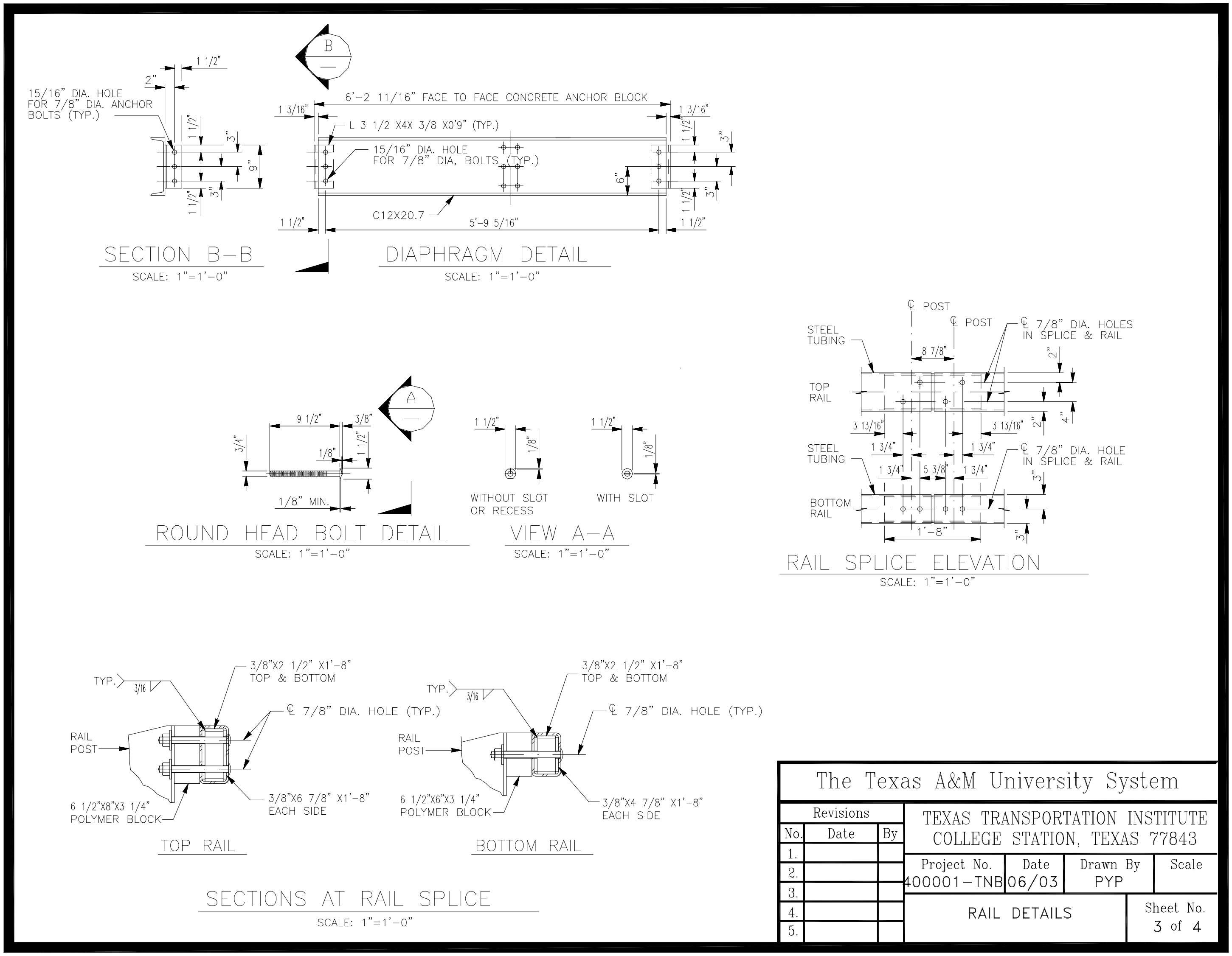


Figure 1. Details of the Tacoma Narrows Bridge Rail (continued).

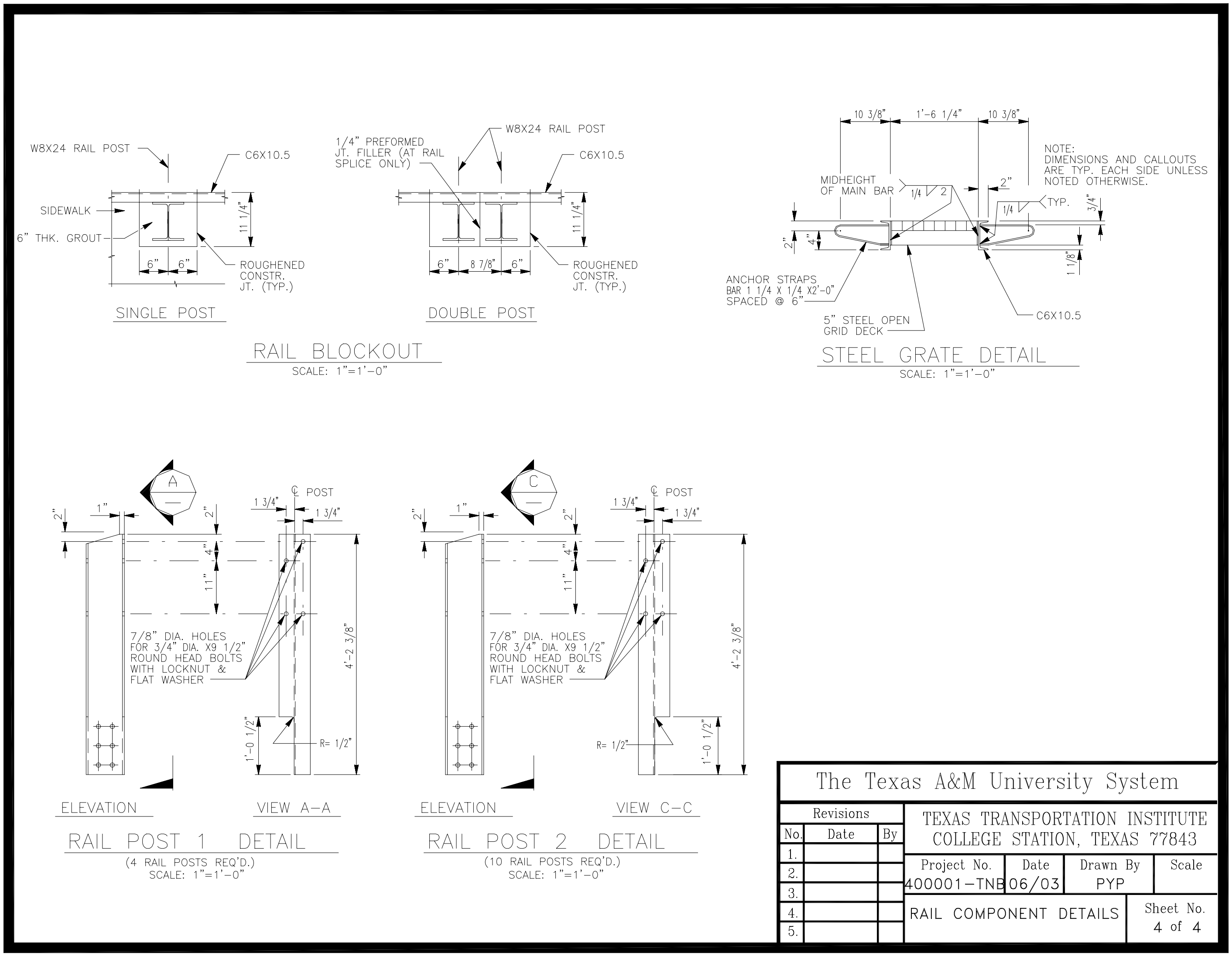


Figure 1. Details of the Tacoma Narrows Bridge Rail (continued).

Figure 2. Tacoma Narrows Bridge Rail prior to testing.

Test Conditions

According to *NCHRP Report 350,* three tests are required to evaluate longitudinal barriers to test level four (TL-4) and are as described below.

> ***NCHRP Report 350* test designation 4-10**: An 820-kg passenger car impacting the barrier at the critical impact point (CIP) of the length of need (LON) at a nominal speed and angle of 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 2000-kg pickup truck impacting the barrier at the CIP of the LON at a nominal speed and angle of 100 km/h and 25 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 2000 kg vehicle.
>
> ***NCHRP Report 350* test designation 4-12**: An 8000-kg single unit box van truck impacting the barrier at the CIP of the LON at a nominal speed and angle of 80 km/h and 15 degrees. The test is intended to evaluate strength of the section in containing and redirecting the 8000 kg vehicle.

The test reported herein corresponds to *NCHRP Report 350* test designation 4-11. According to guidelines of *NCHRP Report 350*, the critical impact point is considered to be 2.0 m upstream of a bridge rail post.

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.

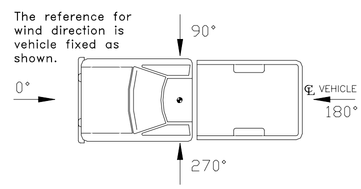
CRASH TEST 400001-TNB1 (*NCHRP REPORT 350* TEST NO. 4-11)

Test Vehicle

A 1999 Chevrolet Cheyenne 2500 pickup truck, shown in figures 3 and 4, was used for the crash test. Test inertia weight of the vehicle was 2067 kg, and its gross static weight was 2067 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 10. 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 8, 2003. No rainfall was recorded within the ten days prior to the test. Weather conditions at the time of testing were as follows: Wind Speed: 29 km/h; Wind Direction: 330 degrees with respect to the vehicle (vehicle was traveling in a southwesterly direction); Temperature: 29 °C; Relative Humidity: 67 percent.



Impact Description

The pickup truck, traveling at a speed of 98.5 km/h, impacted the Tacoma Narrows Bridge Rail 2.0 m upstream of post 4, at an impact angle of 24.4 degrees. At 0.017 s after impact, post 3 deflected slightly toward the field side, and at 0.032 s, post 4 deflected slightly to the field side. The pickup began to redirect at 0.040 s, and the left front wheel steered toward the bridge rail at 0.062 s. The rear of the pickup contacted the bridge rail at 0.181 s. At 0.184 s, the pickup was traveling parallel with the bridge rail at a speed of 82.5 km/h. At 0.299 s, the pickup lost contact with the bridge rail and was traveling at a speed of 80.4 km/h and an exit angle of 5.6 degrees. Brakes on the pickup were applied 1.5 s after impact. The pickup subsequently yawed clockwise and came to rest facing the installation 61.8 m downstream of the point of impact and 0.8 m forward of the face of the bridge rail. Sequential photographs of the test period are shown in appendix C, figures 11 and 12.

Figure 3. Vehicle/installation geometrics for test 400001-TNB1.

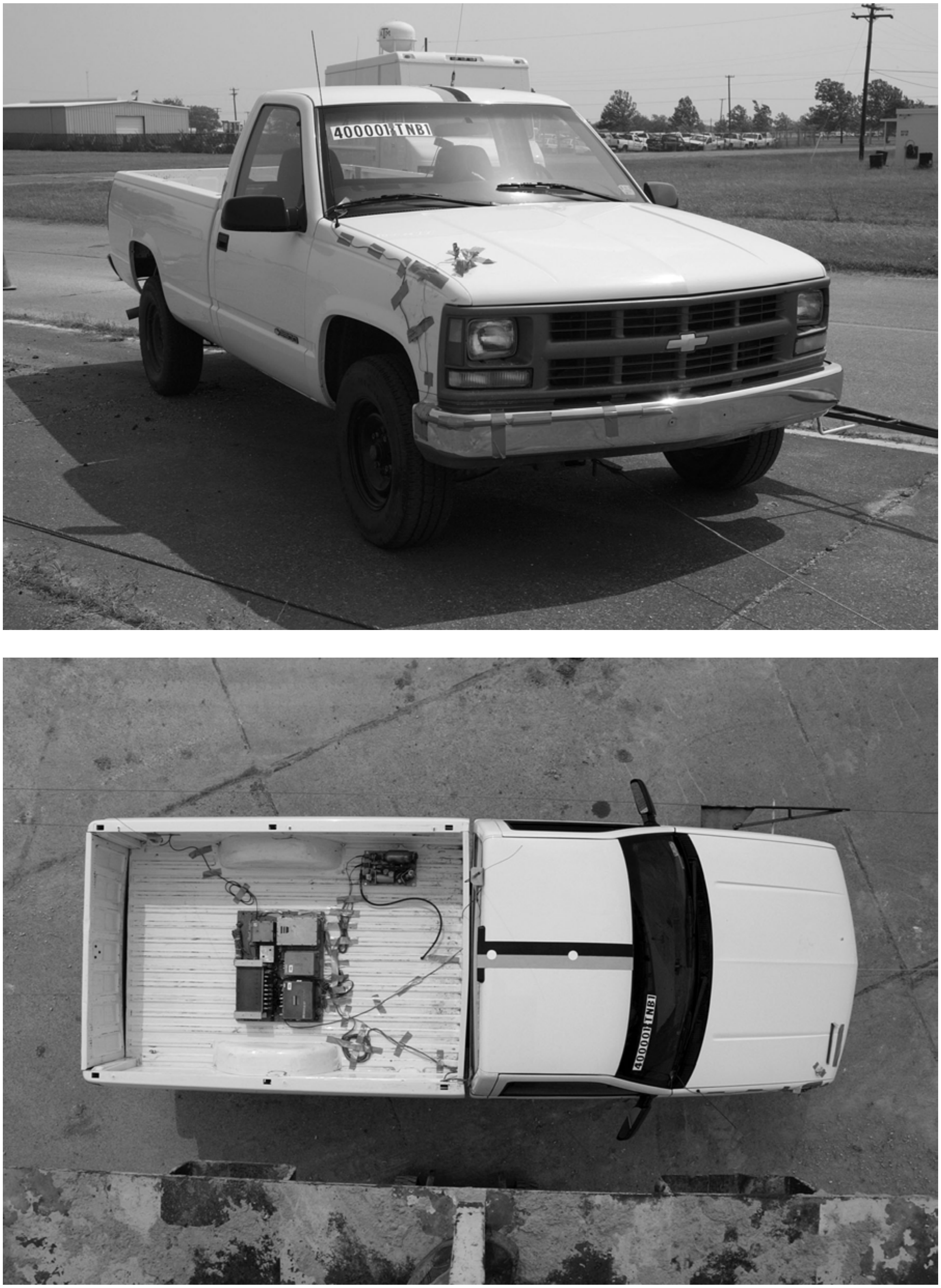


Figure 4. Vehicle before test 400001-TNB1.

Damage to Test Article

Damage to the bridge rail was minor, as shown in figures 5 and 6. There were tire marks and scrapes along the face of the tubular rail elements from the point of impact (2.0 m upstream of post 4) for a distance of the length of contact of the vehicle with the rail elements of 3.88 m. No residual measurable movement was noted in the posts or the rail elements after the test.

Vehicle Damage

Damage to the pickup is shown in figure 7. Structural damage was imparted to the right upper and lower A-arm, right front frame rail, and the floor pan. Also damaged were the front bumper, grill, hood, radiator, right front quarter panel, right door, right rear exterior bed, and rear bumper. The right front and right rear wheel rims were deformed and both tires were deflated. Maximum exterior crush to the pickup was 560 mm in the frontal plane at the right front corner at bumper height. Maximum occupant compartment deformation was 84 mm in the right side kickpanel area. Photographs of the interior of the pickup are shown in figure 8. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 2 and 3.

Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle c.g., were digitized to compute occupant impact velocity and ridedown accelerations. 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 5.4 m/s at 0.095 s, maximum 0.010-s ridedown acceleration was -7.8 g's from 0.101 to 0.111 s, and the maximum 0.050-s average was -9.3 g's between 0.036 and 0.086 s. In the lateral direction, the occupant impact velocity was 7.5 m/s at 0.095 s, the highest 0.010-s occupant ridedown acceleration was -10.7 g's from 0.231 to 0.241 s, and the maximum 0.050-s average was -12.0 g's between 0.030 and 0.080 s. These data and other information pertinent to the test are presented in figure 9. Vehicle angular displacements and accelerations versus time traces are shown in appendix D, figures 13 through 19.

Figure 5. Vehicle trajectory after test 400001-TNB1.

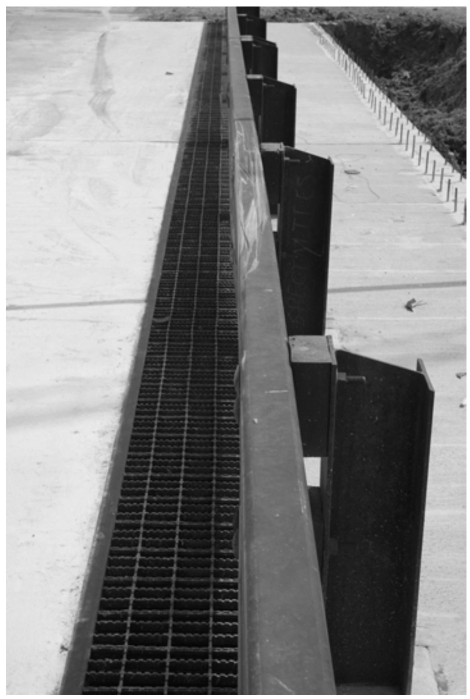


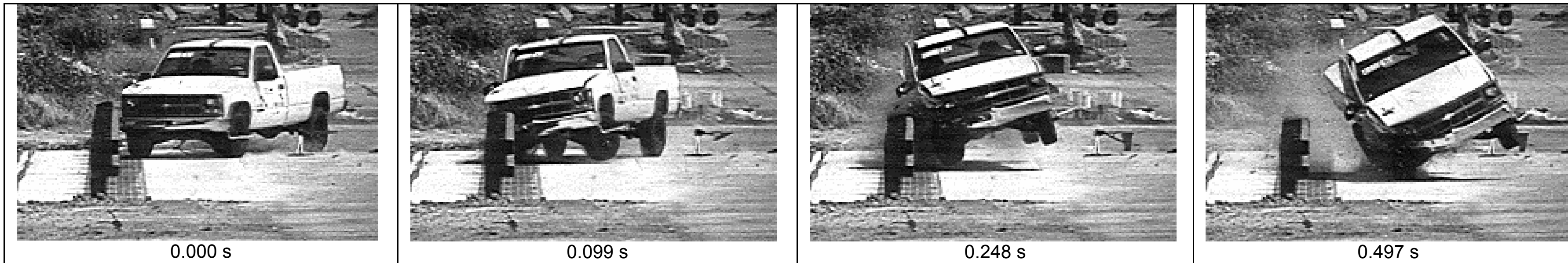
Figure 6. Installation after test 400001-TNB1.

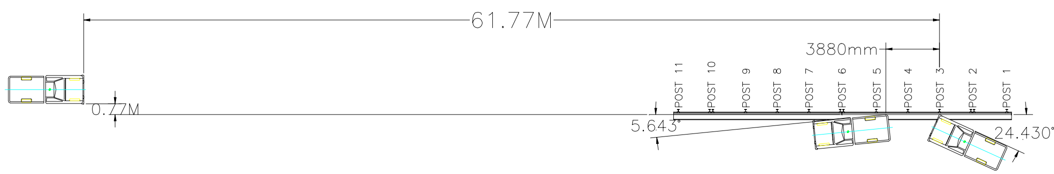
Figure 7. Vehicle after test 400001-TNB1.

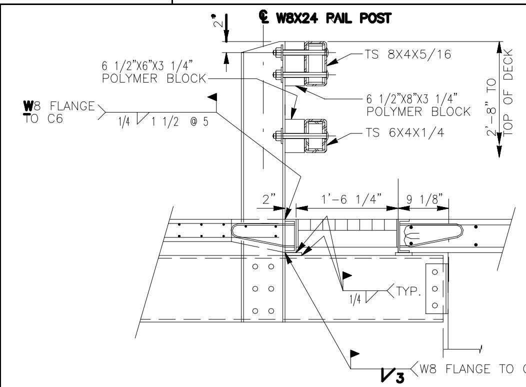
Before Test

After Test

Figure 8. Interior of vehicle for test 400001-TNB1.







General Information
- Test Agency .... Texas Transportation Institute
- Test No. 400001-TNB1
- Date 05/08/2003

Test Article
- Type .... Retrofit Bridge Rail
- Name .... Tacoma Narrows Bridge Rail
- Installation Length (m) 24.4
- Material or Key Elements..... TS200x100x8 & TS150x100x6 Rails on W200x36 Posts

Soil Type and Condition......... Bridge Deck, Dry

Test Vehicle
- Type .... Production
- Designation 2000P
- Model .... 1999 Chevrolet 2500 pickup
- Mass (kg)
  - Curb 2114
  - Test Inertial 2067
  - Dummy .... N/A
  - Gross Static 2067

Impact Conditions
- Speed (km/h)............................... 98.5
- Angle (deg).................................. 24.4

Exit Conditions
- Speed (km/h)............................... 80.4
- Angle (deg).................................. 5.6

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction 5.4
  - y-direction 7.5
- THIV (km/h)................................. 32.6
- Ridedown Accelerations (g's)
  - x-direction .... -7.8
  - y-direction .... -10.7
- PHD (g's)..................................... 10.9
- ASI 1.57
- Max. 0.050-s Average (g's)
  - x-direction .... -9.3
  - y-direction .... -12.0
  - z-direction .... -5.6

Test Article Deflections (m)
- Dynamic............................... N/A
- Permanent 0.045
- Working Width 0.50

Vehicle Damage
- Exterior
  - VDS 01LFQ5
  - CDC............................... 11FYEW3
- Maximum Exterior
  - Vehicle Crush (mm)........ 560
- Interior
  - OCDI.............................. FS0112000
- Max. Occ. Compartment
  - Deformation (mm)........... 84

Post-Impact Behavior
(during 2.7 s after impact)
- Max. Yaw Angle (deg) 49.4
- Max. Pitch Angle (deg) .... -6.9
- Max. Roll Angle (deg).......... 24.7

Figure 9. Summary of results for test 400001-TNB1, *NCHRP Report 350* test 4-11.

SUMMARY AND CONCLUSIONS

ASSESSMENT OF TEST RESULTS

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

Structural Adequacy

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

Results: The Tacoma Narrows Bridge Rail contained and redirected the pickup truck. The pickup did not penetrate, override, or underride the installation. No measurable deflection occurred.

Occupant Risk

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

Results: No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 84 mm in the right side kickpanel area.

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

Results: The pickup 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.

Results: The pickup came to rest 10.3 m downstream of impact and 0.8 m forward of the traffic face of the bridge rail.

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

Results: Longitudinal occupant impact velocity was 5.4 m/s and longitudinal ridedown acceleration was -7.8 g's.

M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device.

Results: Exit angle at loss of contact with the bridge rail was 5.6 degrees, which was 23 percent of the impact angle.

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

Passenger Compartment Intrusion

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

Loss of Vehicle Control

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

Physical Threat to Workers or Other Vehicles

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

No debris was present.

Vehicle and Device Condition

1. **Vehicle Damage**
   a. None
   b. Minor scrapes, scratches or dents
   c. Significant cosmetic dents
   d. Major dents to grill and body panels
   e. Major structural damage
2. **Windshield Damage**
   a. None
   b. Minor chip or crack
   c. Broken, no interference with visibility
   d. Broken or shattered, visibility restricted but remained intact
   e. Shattered, remained intact but partially dislodged
   f. Large portion removed
   g. Completely removed
3. **Device Damage**
   a. None
   b. Superficial
   c. Substantial, but can be straightened
   d. Substantial, replacement parts needed for repair
   e. Cannot be repaired

CONCLUSIONS

The Tacoma Narrows Bridge Rail met the required specifications for *NCHRP Report 350* test 4-11, as shown in table 1. No distress was noted in the bridge railing or deck. The vehicle was stable and the snagging on the system was minimal. Therefore, Tests 4-10 and 4-12 from the previous Illinois two tube crash tests indicate there will be good performance of this system under the same test conditions.

Table 1. Performance evaluation summary for test 400001-TNB1, *NCHRP Report 350* test 4-11.

Test Agency: Texas Transportation Institute | Test No.: 400001-TNB1 | Test Date: 05/08/2003

***NCHRP Report 350* Test 4-11 Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy A. *Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable*	The Tacoma Narrows Bridge Rail contained and redirected the pickup truck. The pickup did not penetrate, override, or underride the installation. No measurable deflection occurred.	Pass
Occupant Risk D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*	No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 84 mm in the right side kickpanel area.	Pass
F. *The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.*	The pickup remained upright during and after the collision period.	Pass
Vehicle Trajectory K. *After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*	The pickup came to rest 10.3 m downstream of impact and 0.8 m forward of the traffic face of the bridge rail.	Pass*
L. *The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.*	Longitudinal occupant impact velocity was 5.4 m/s and longitudinal ridedown acceleration was -7.8 g's.	Pass
M. *The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.*	Exit angle at loss of contact with the bridge rail was 5.6 degrees, which was 23 percent of the impact angle.	Pass*

*Criterion K and M are preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

The crash test and data analysis procedures were in accordance with guidelines presented in *NCHRP Report 350*. Brief descriptions of these procedures are presented as follows.

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO® Model 2262CA, piezoresistive accelerometers with a $\pm$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 $\pm$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 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 SAE J211 class 180 phaseless digital filtering and vehicle impact velocity.

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

The Test Risk Assessment Program (TRAP) uses the data from WinDigit to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-ms average ridedown acceleration. WinDigit calculates change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter, and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP. TRAP uses the data from the yaw, pitch, and roll rate transducers to compute angular displacement in degrees at 0.0001-s intervals and then plots: yaw, pitch, and roll versus time. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate systems being initial impact.

ANTHROPOMORPHIC DUMMY INSTRUMENTATION

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

PHOTOGRAPHIC INSTRUMENTATION AND DATA PROCESSING

Photographic coverage of the test included three high-speed cameras: one overhead with a field of view perpendicular to the ground and directly over the impact point; one placed behind the installation at an angle; and a third placed to have a field of view parallel to and aligned with the installation at the downstream end. A 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 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 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

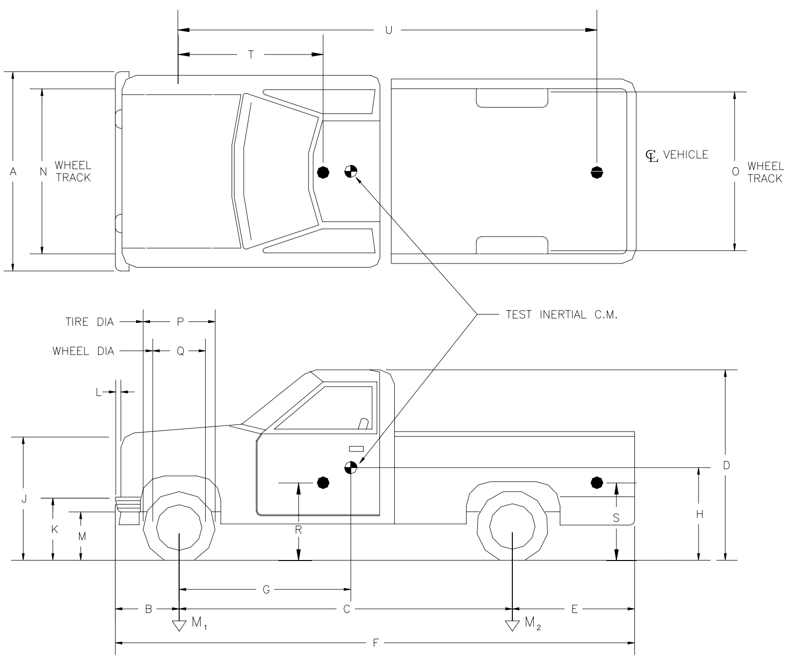
DATE: 05/08/03 TEST NO.: 400001-TNB1 VIN NO.: 1GCGC24R8XR703099

YEAR: 1999 MAKE: Chevrolet MODEL: Cheyenne 2500

TIRE INFLATION PRESSURE: ______ ODOMETER: 155933 TIRE SIZE: 245 75 R16

MASS DISTRIBUTION (kg) LF 607 RF 573 LR 432 RR 455

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: V-8

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

8 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A	1880	E	1310	J	1038	N	1590	R	750
B	810	F	5470	K	635	O	1610	S	900
C	3350	G	1437.6	L	70	P	725	T	1460
D	1820	H		M	415	Q	440	U	3360

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1220	1180	
M_2	894	887	
M_T	2114	2067	

Figure 10. Vehicle properties for test 400001-TNB1.

Table 2. Exterior crush measurements for test 400001-TNB1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage Width** (CDC)	Direct Damage Max*** Crush	Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
1	At front bumper	1060	560	660	0	80	240	320	430	560	+330
2	Above front bumper	1060	500	1180	50	110	Wheel Well		350	500	+1700

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

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

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

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

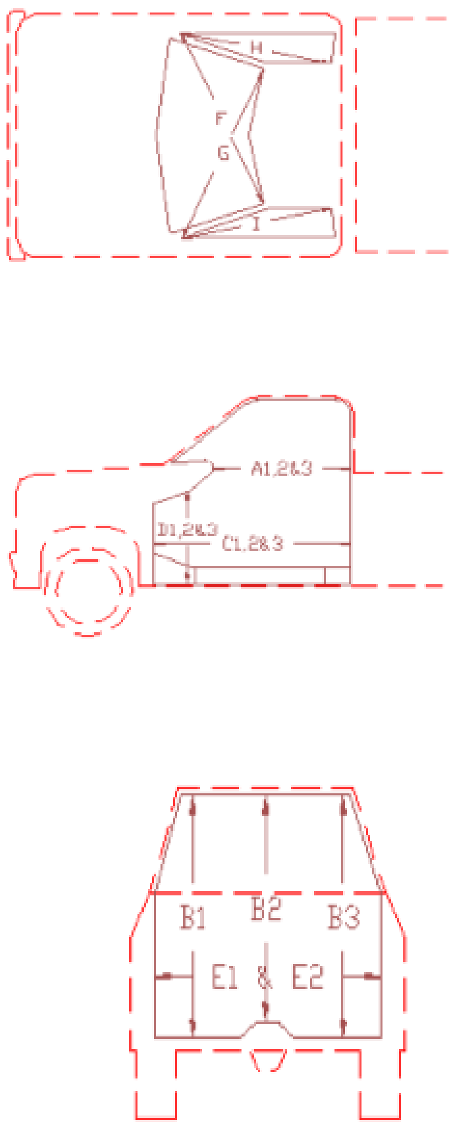
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 3. Occupant compartment measurements for test 400001-TNB1.

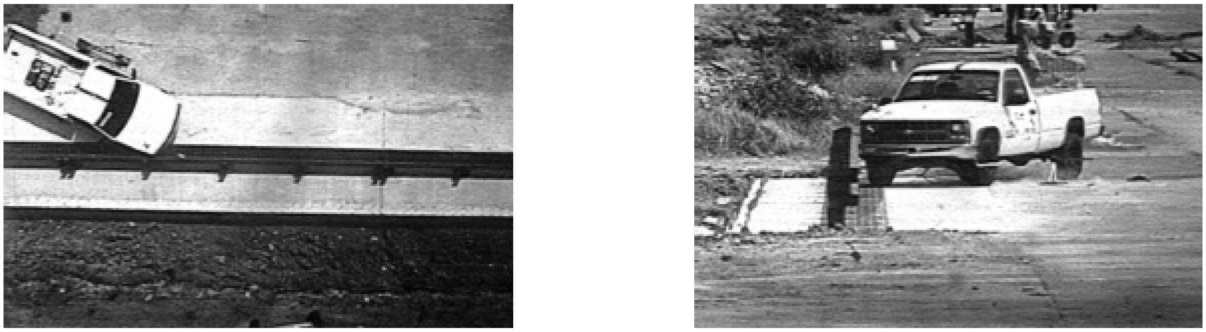
Truck

Occupant Compartment Deformation

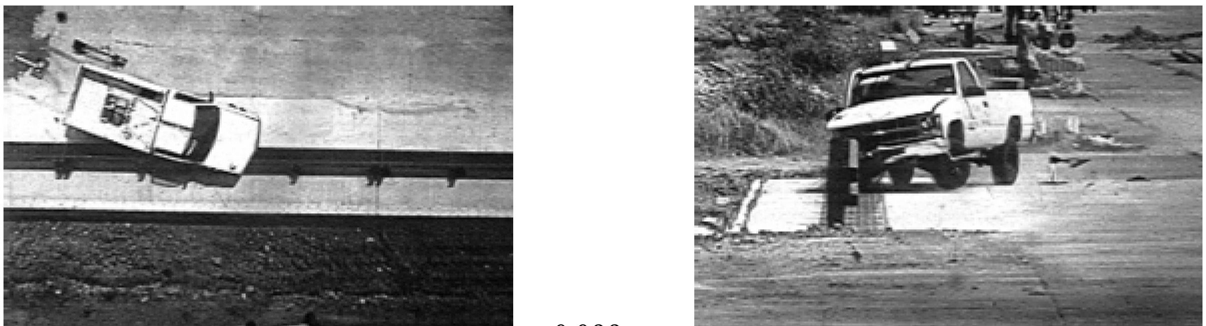


	BEFORE	AFTER
A1	870	885
A2	945	950
A3	933	924
B1	1074	1074
B2	1026	950
B3	1072	1000
C1	1371	1371
C2		
C3	1370	1355
D1	325	355
D2	158	135
D3	307	285
E1	1585	1570
E2	1590	1600
F	1450	1455
G	1450	1455
H	1250	1260
I	1250	1235
J	1520	1436

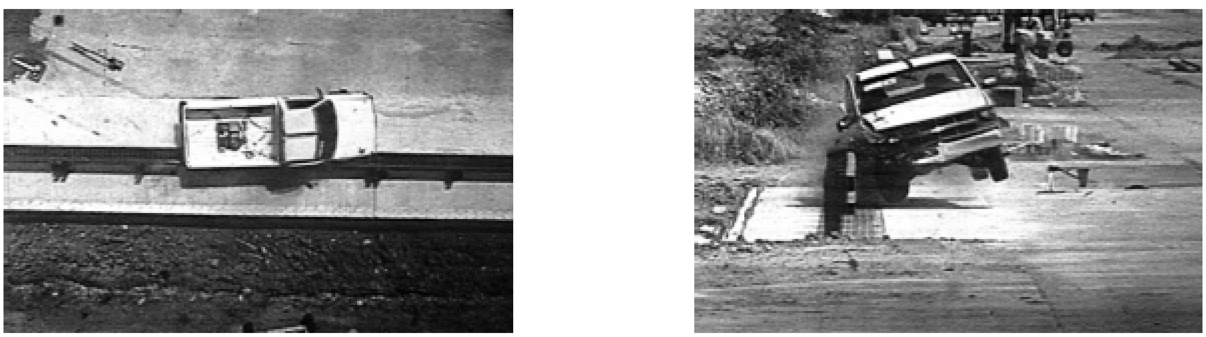
APPENDIX C. SEQUENTIAL PHOTOGRAPHS



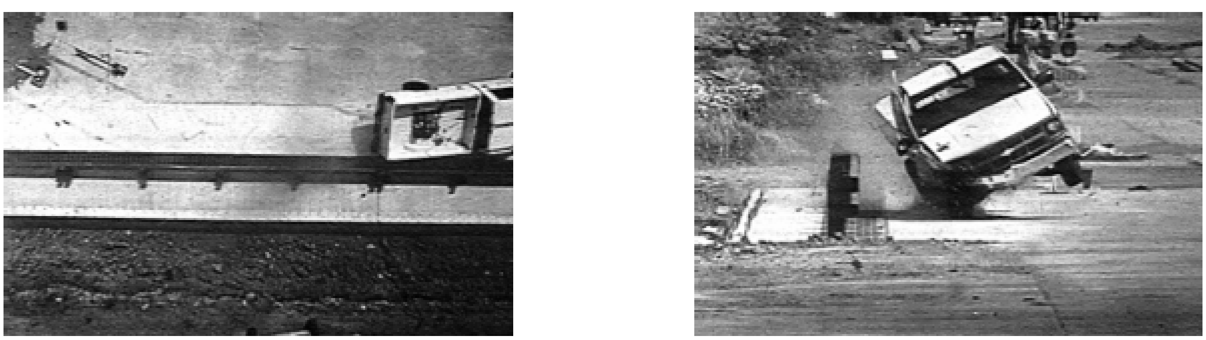
0.000 s



0.099 s

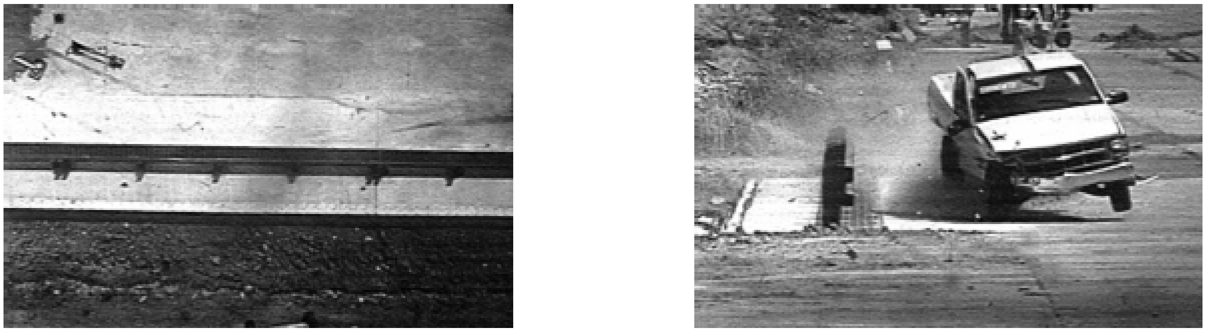


0.248 s

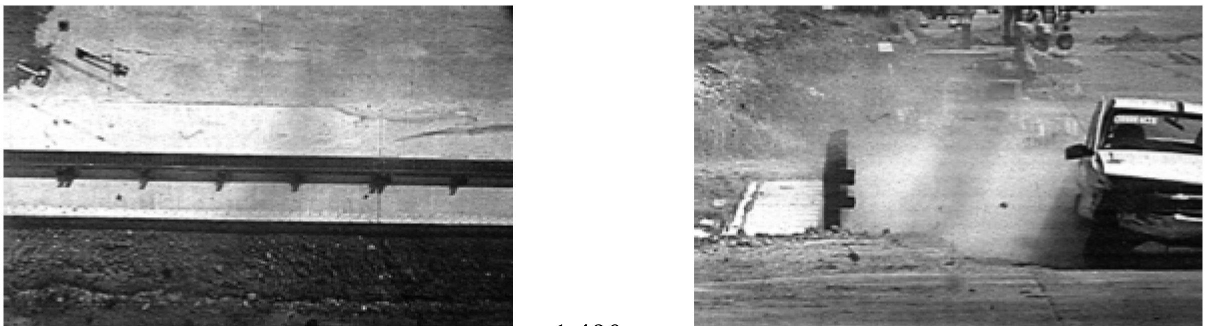


0.497 s

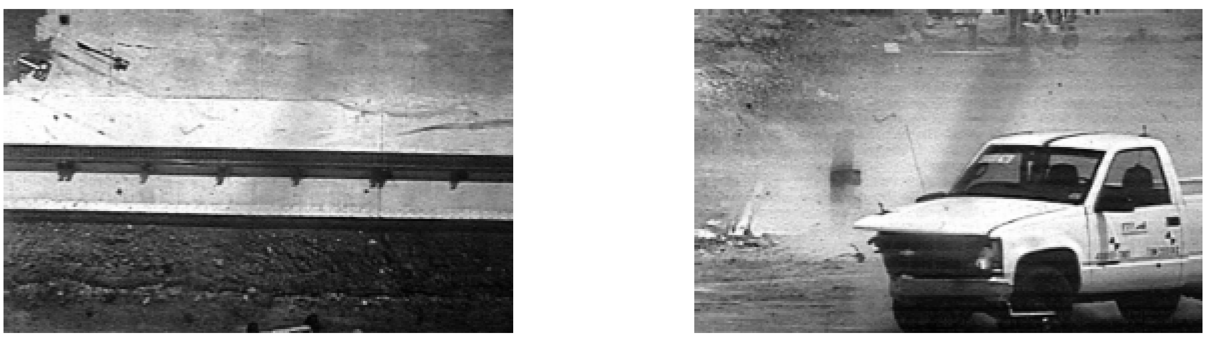
Figure 11. Sequential photographs for test 400001-TNB1
(overhead and frontal views).



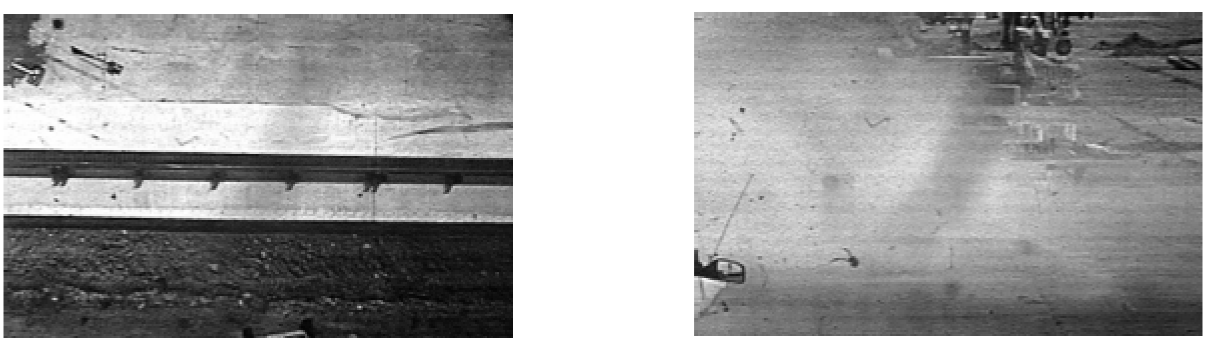
0.745 s



1.490 s

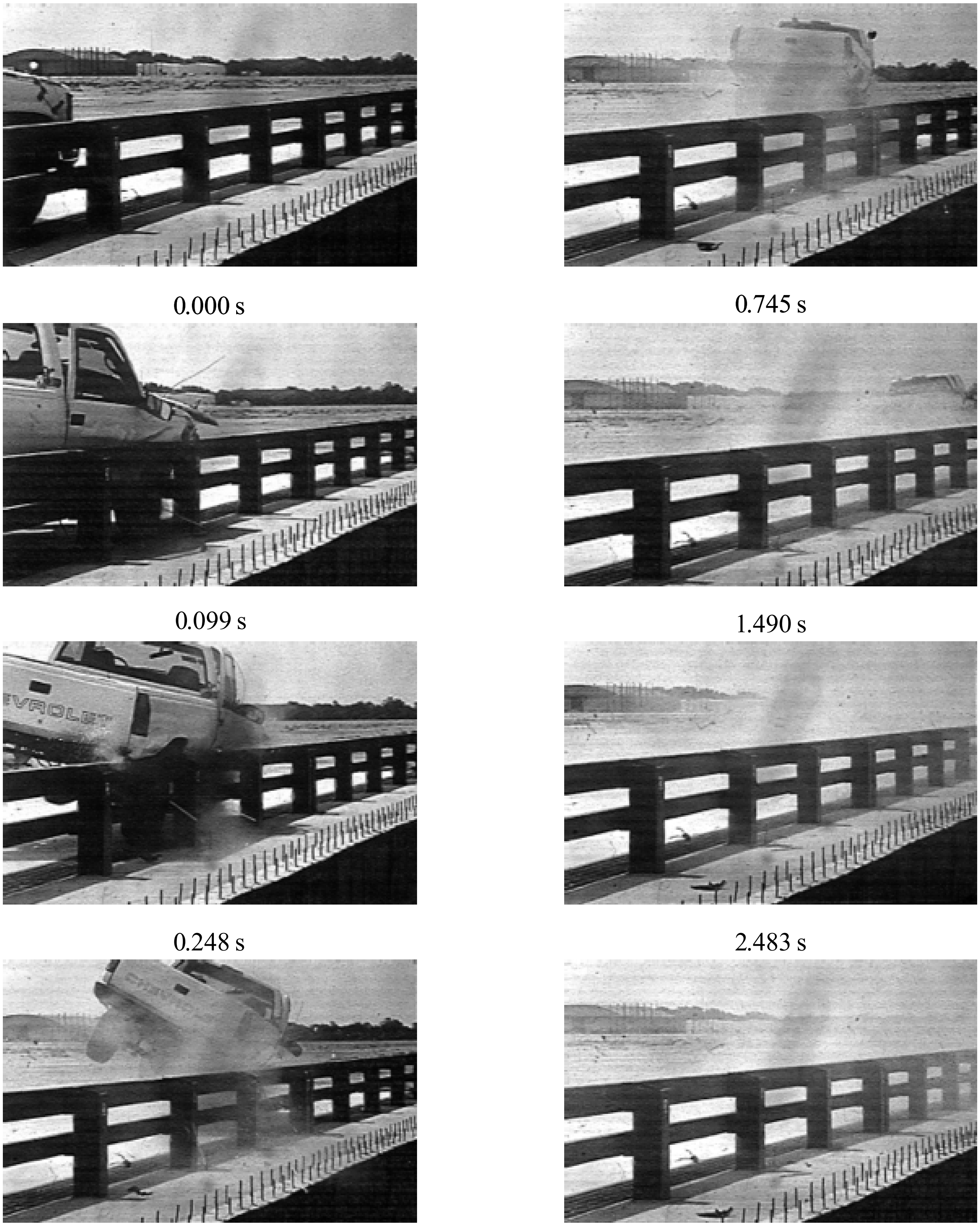


2.483 s



4.717 s

Figure 11. Sequential photographs for test 400001-TNB1
(overhead and frontal views) (continued).



0.000 s
0.745 s
0.099 s
1.490 s
0.248 s
2.483 s
0.497 s
4.717 s

Figure 12. Sequential photographs for test 400001-TNB1 (rear view).

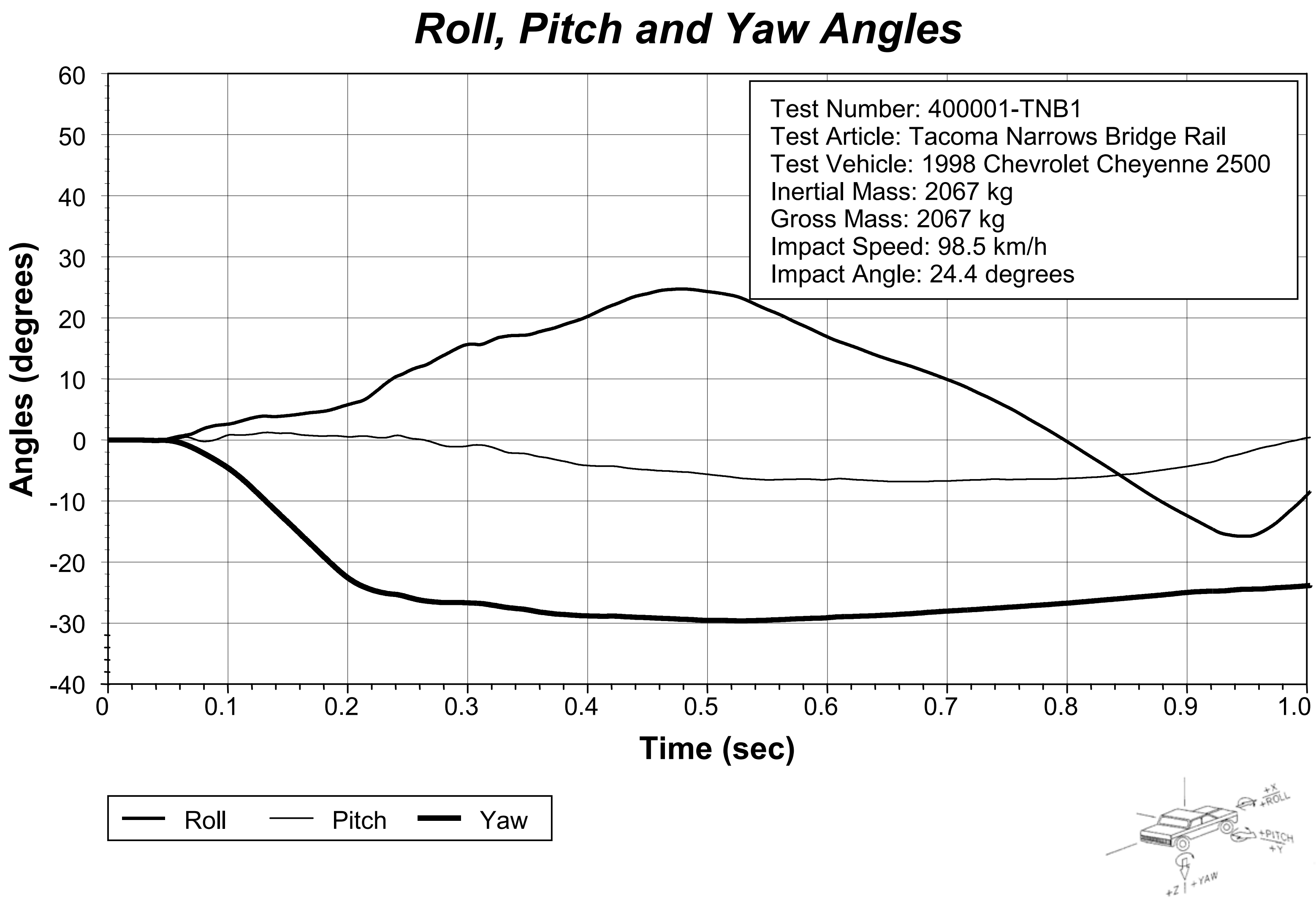


Figure 13. Vehicle angular displacements for test 400001-TNB1.

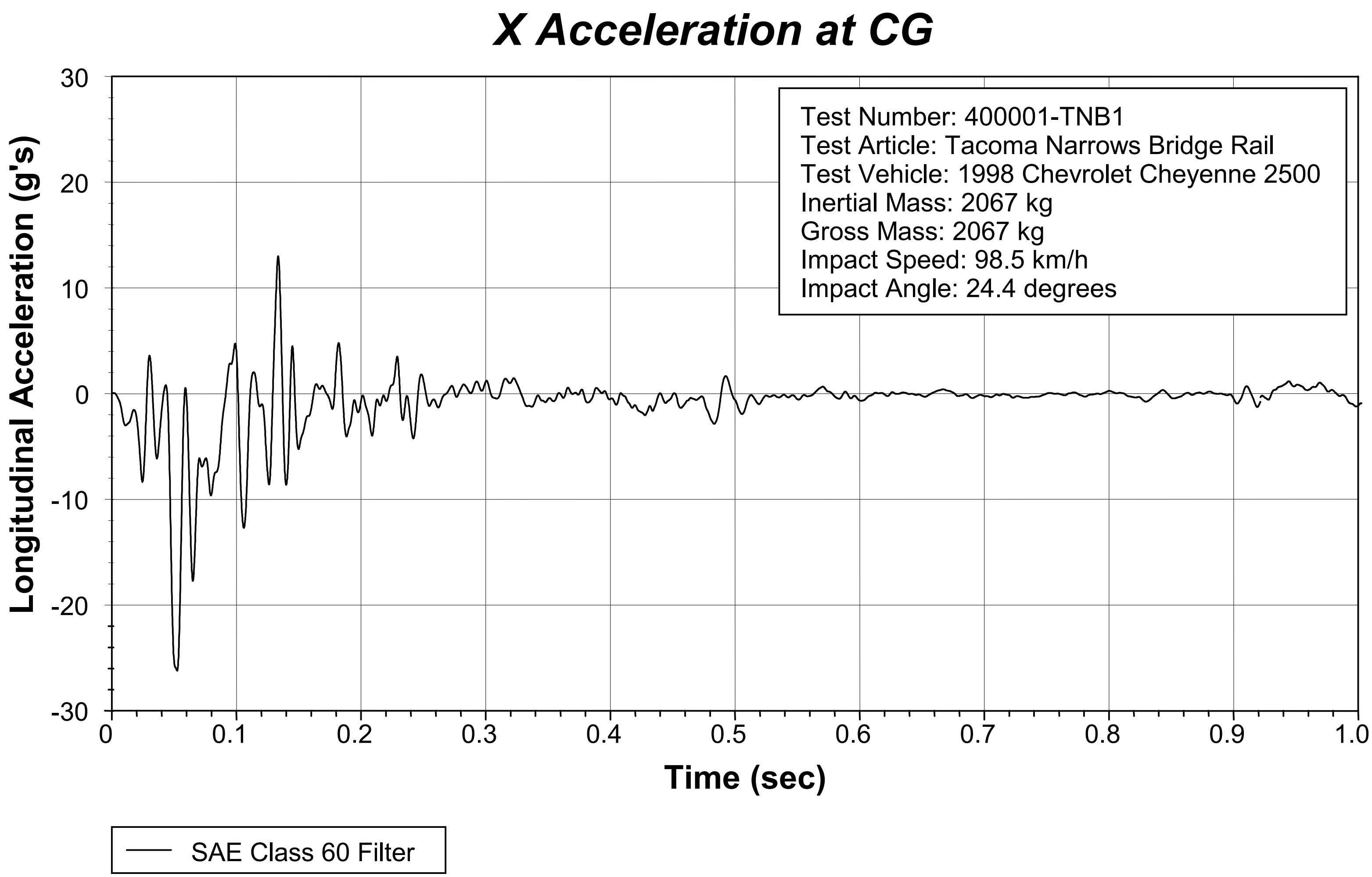


Figure 14. Vehicle longitudinal accelerometer trace for test 400001-TNB1 (accelerometer located at center of gravity).

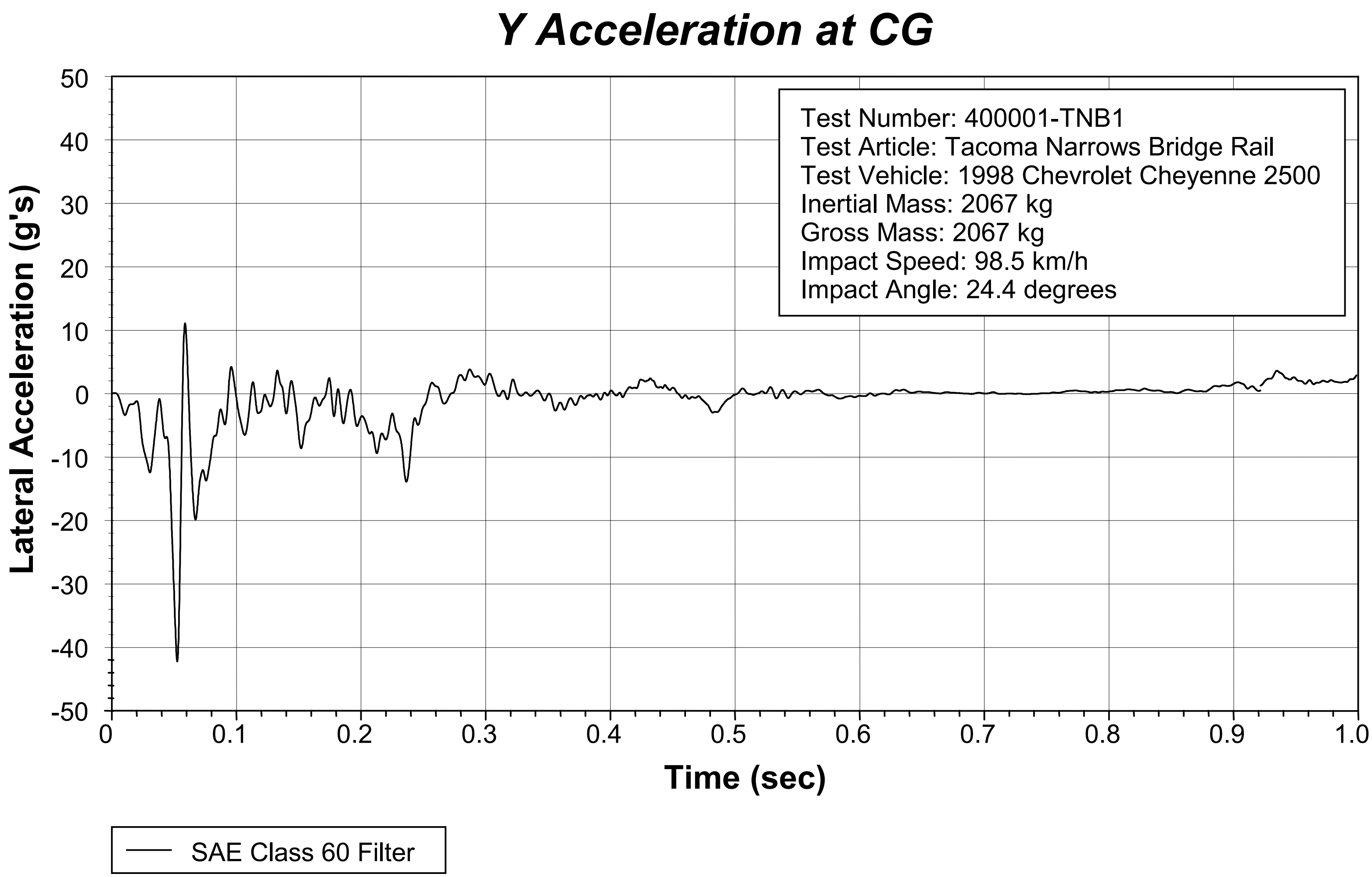


Figure 15. Vehicle lateral accelerometer trace for test 400001-TNB1 (accelerometer located at center of gravity).

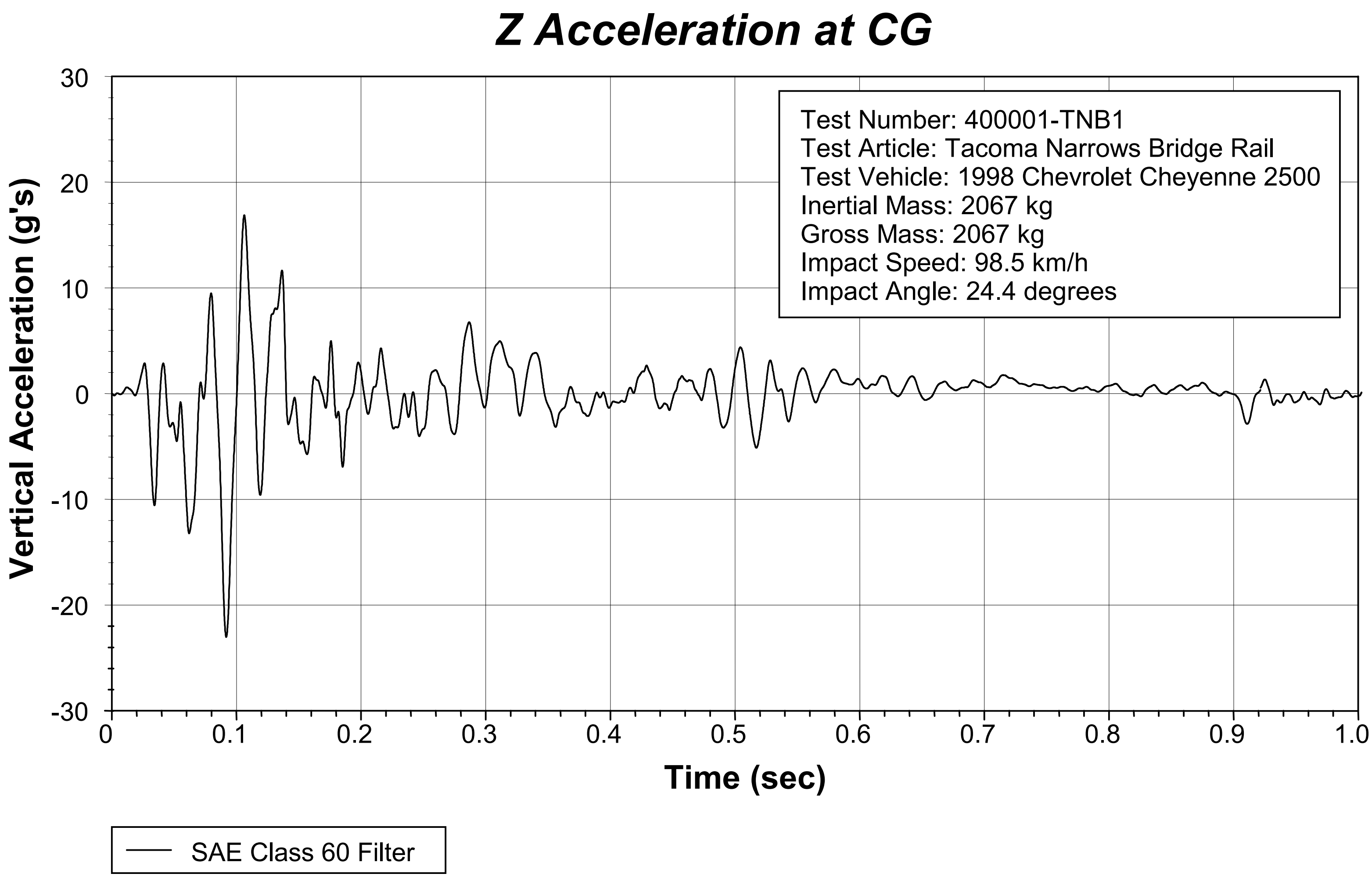


Figure 16. Vehicle vertical accelerometer trace for test 400001-TNB1
(accelerometer located at center of gravity).

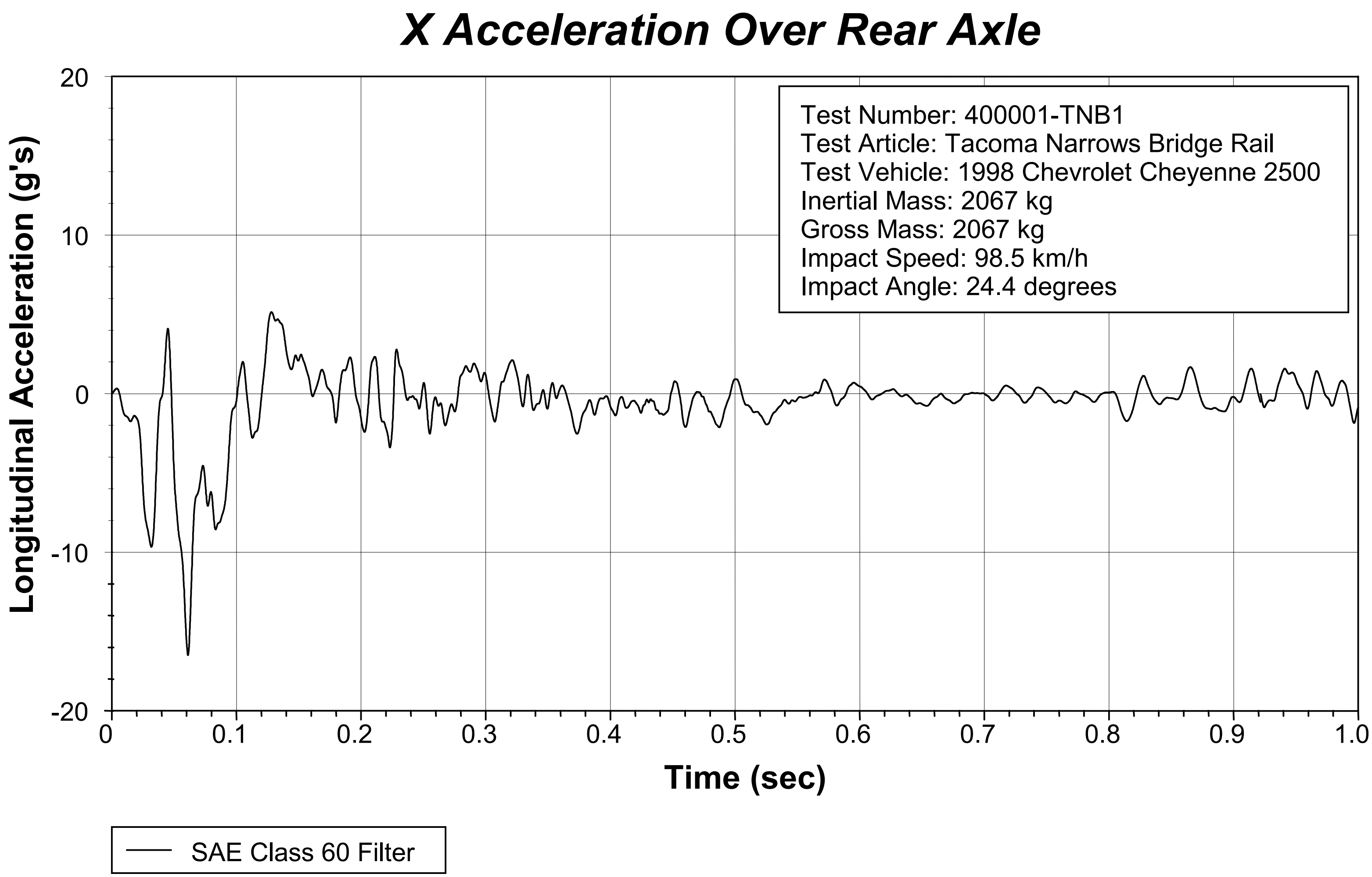


Figure 17. Vehicle longitudinal accelerometer trace for test 400001-TNB1
(accelerometer located over rear axle).

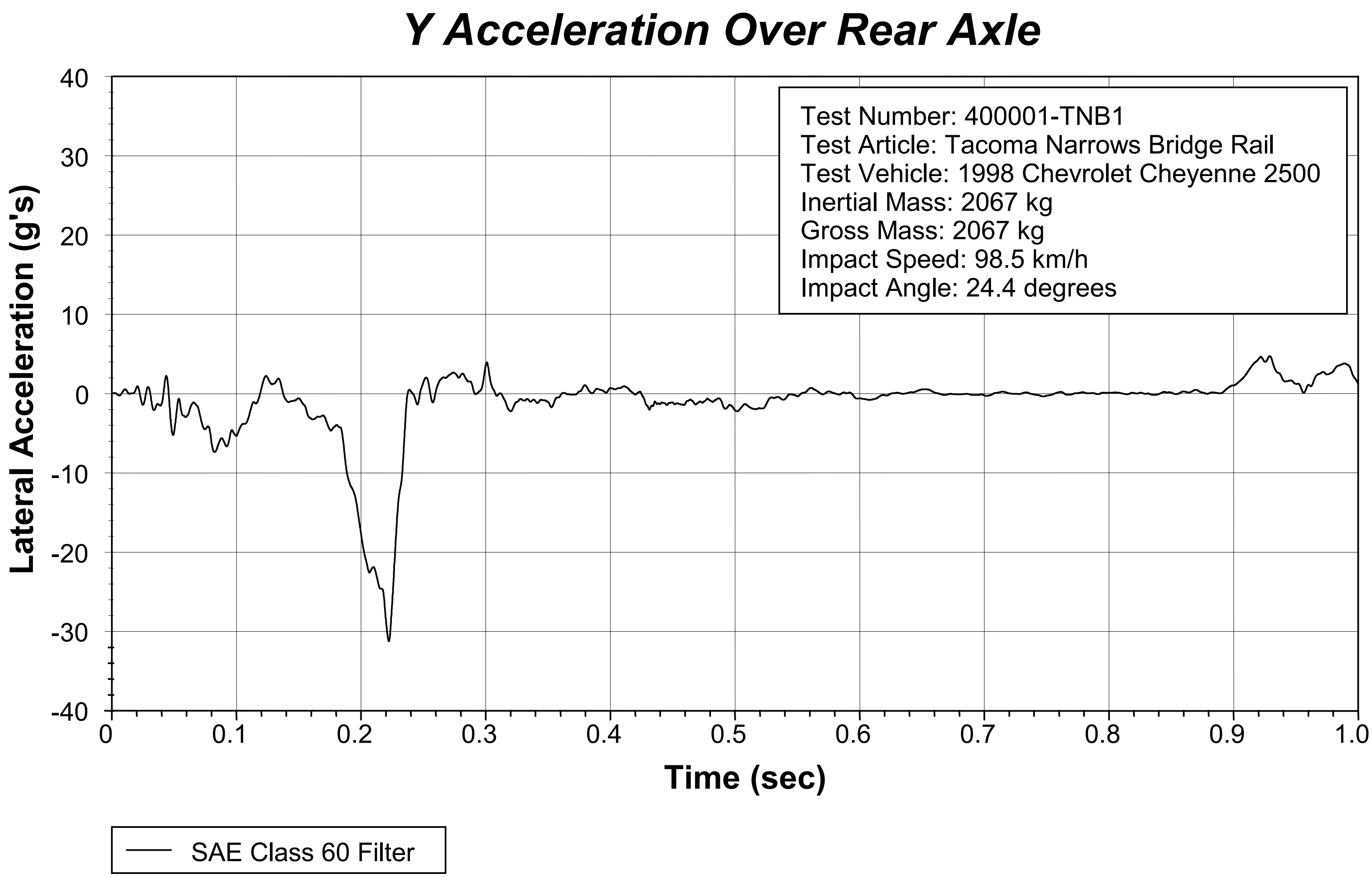


Figure 18. Vehicle lateral accelerometer trace for test 400001-TNB1 (accelerometer located over rear axle).

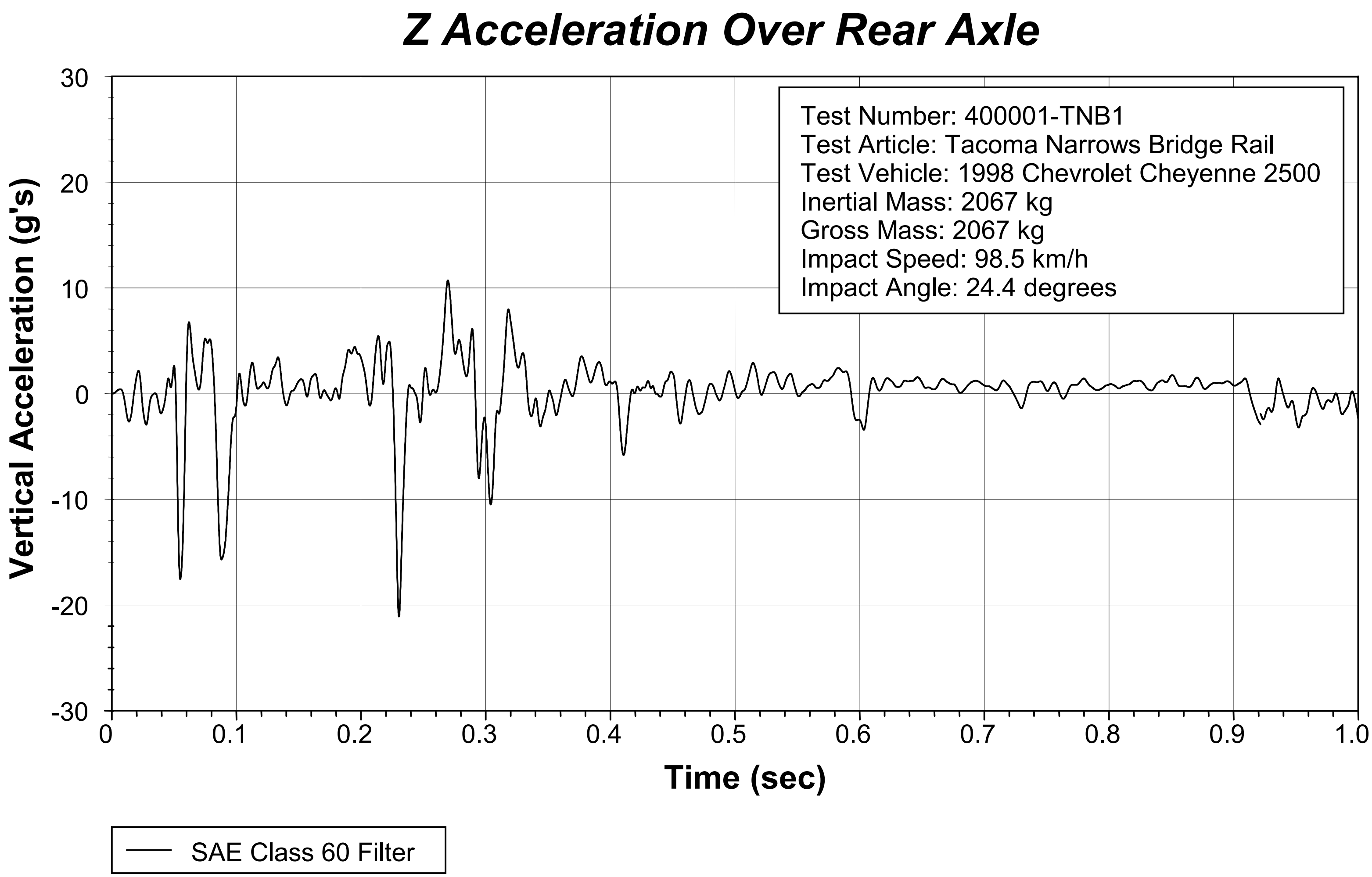


Figure 19. Vehicle vertical accelerometer trace for test 400001-TNB1
(accelerometer located over rear axle)

REFERENCES

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

2. C.E. Buth, T.J. Hirsch, W.L. Menges, "Testing of New Bridge Rail and Transition Designs, Appendix C. Illinois 2399-1 Bridge Railing," Federal Highway Administration Contract DTFH61-86-C-00071, Washington D.C., 1993.

3. C.E. Buth, T.J. Hirsch, W.L. Menges, "Testing of New Bridge Rail and Transition Designs, Appendix C. Illinois Side-Mounted Bridge Rail," Federal Highway Administration Contract DTFH61-86-C-00071, Washington D.C., 1993.