GUARDRAIL TESTING – MODIFIED ECCENTRIC LOADER TERMINAL (MELT) AT NCHRP 350 TL-2

Dean C. Alberson, Wanda L. Menges, and Rebecca R. Haug

Prepared for
The New England Transportation Consortium

July 2002

NETCR 35 Project No. 00-5

This report, prepared in cooperation with the New England Transportation Consortium, does not constitute a standard, specification, or regulation. The contents of this report reflect the views of the author(s) who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the views of the New England Transportation Consortium or the Federal Highway Administration.

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NETCR 35	N/A	N/A

4. Title and Subtitle	5. Report Date
GUARDRAIL TESTING - MODIFIED ECCENTRIC LOADER TERMINAL (MELT) AT NCHRP 350 TI-2	July 2002
	6. Performing Organization Code N/A
7. Author(s) Dean C. Alberson, Wanda L. Menges, and Rebecca R. Haug	8. Performing Organization Report No. N/A
9. Performing Organization Name and Address Texas Transportation Institute Safety and Structural Systems Texas A&M University System College Station, Texas 77843-3135	10 Work Unit No. (TRAIS) N/A
	11. Contract or Grant No. N/A
12. Sponsoring Agency Name and Address New England Transportation Consortium 179 Middle Turnpike University of Connecticut, U-5202 Storrs, CT 06269-5202	13. Type of Report and Period Covered Final Report April 2000-May 2002
	14. Sponsoring Agency Code NETC 00-5

15 Supplementary Notes
Research Study Title: Guardrail Testing-Modified Eccentric Loader Terminal (MELT) at NCHRP TL-2
Name of Contacting Representative: Gerry McCarthy, Coordinator, NETC

The objective of this study, as stated in the NETC request for proposal is to "…conduct the testing needed for FHWA consideration of the acceptability of the NETC MELT… at *NCHRP Report 350* Test Level 2 (TL-2) criteria, and to document the testing and the results of the testing in sufficient detail for FHWA consideration. The ultimate goal is to achieve FHWA approval of the NETC MELT as an approved TL-2 guardrail terminal." *NCHRP Report 350* TL-2 evaluates the impact performance of the guardrail terminal when impacted by a vehicle traveling 70 km/h (43.5 mi/h) rather than, as previously tested, the TL-3 impact speed of 100 km/h (62.2 mi/h). NETC contracted to perform *NCHRP Report 350* test designations 2-30 and 2-31. *NCHRP Report 350* test designation 2-30 involves an 820-kg passenger car impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 0 degree with the quarter point of the vehicle aligned with the centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria. *NCHRP Report 350* test designation 2-31 involves a 2000-kg pickup truck impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 0 degree with the centerline of the vehicle aligned with the centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria. Reported herein are the details of the NETC MELT installation, description of the two full-scale crash tests performed, and the results and assessment of those tests. The NETC MELT performed acceptably for *NCHRP Report 350* test designations 2-30 and 2-31.

17. Key Words	18. Distribution Statement
Terminal, MELT, modified eccentric loader terminal, end treatment, crash testing, roadside safety	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	21. Price
Unclassified	Unclassified	75	

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

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square 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

TABLE OF CONTENTS (continued)

Section | Page

LIST OF FIGURES

LIST OF FIGURES (continued)

Figure		Page

LIST OF TABLES

INTRODUCTION

PROBLEM

The safe termination of guardrails has been a challenge ever since the risk of impacting the exposed end of the beam was identified. An untreated rail end exposes the errant vehicle to the potential of the rail spearing the vehicle, intruding into the occupant compartment, and bringing the vehicle to a violently abrupt stop. Crashworthy termination of a guardrail installation is essential anytime a guardrail is terminated within the clear zone of the highway. Methodologies for treating the terminal end of a guardrail include, but are not limited to, turning down the end, burying into a backslope, flaring away from the travel-way, and dissipating energy with heads that mount to the end of the rail element.

Twisting and turning the rail end down creates vehicle instability when struck end-on and may produce rolling and/or vaulting of the errant vehicle that impacts the start of the rail installation. Burying the exposed end of a rail element into a backslope is crashworthy, but not always practical due to the additional space and fill material that may be required.

The safety performance of the breakaway cable terminal (BCT)family of flared/buffered end-terminals (i.e., BCT, eccentric loader terminal (ELT), modified eccentric loader terminal (MELT)) are very sensitive to installation errors. The BCT in particular has exhibited poor performance when struck head-on by an 820 kg (1808 lb) passenger vehicle at speeds as low as 70 km/h.[1-4] When impacted head-on by an errant small passenger vehicle, the rail initially buckles at or near post number two or three. As the nose of the rail swings away from the vehicle, an elbow is formed in the rail. The eccentric impact of the vehicle with the buffered end and post number one induces a yaw rotation which exposes the side of the vehicle to the elbow in the rail. The impact of the side of the vehicle with the elbow and post generally results in excessive intrusion into the occupant compartment at the driver's door or rear passenger compartment. This type of behavior was exhibited by the BCT guardrail terminal under both TL-2 and TL-3 impact conditions.

Numerous proprietary guardrail terminals have been developed and successfully crash tested to guidelines in National Cooperative Highway Research Program (NCHRP) *Report 350* "Recommended Procedures for the Safety Performance Evaluation of Highway Features."[5] A proprietary flared back guardrail terminal with a buffered end was developed to solve many of the problems associated with the MELT and BCT terminals. The slotted rail terminal (SRT) controls the lengths and location of the buckled rail sections by placing control slots into the rail elements that effectively reduce the column strength of the rail.[6-8] In addition, proprietary energy absorbing heads that are mounted to the end of the guardrail element have also been developed and successfully crash tested to *NCHRP Report 350* standards.[9-12] These guardrail terminal heads remove kinetic energy by either plastically deforming the W-beam rail element in a controlled manner or shearing the rail metal longitudinally.

Despite the development of new guardrail terminals that meet the criteria of *NCHRP Report 350*, thousands of flared/buffered end-terminals, such as the MELT, BCT and ELT, are still in service along the highways. The capital cost to the States to replace the existing installations is phenomenal. In addition, FHWA policy in regard to crash testing highway safety appurtenances has resulted in most hardware being tested only to Test Level 3 (TL-3). This has left non-proprietary hardware that may be obsolete by TL-3 standards also unavailable for use at Test Level 2 (TL-2) sites.

OBJECTIVES/SCOPE OF RESEARCH

The objective of this study, as stated in the NETC request for proposal, is to "...conduct the testing needed for FHWA consideration of the acceptability of the NETC MELT … at *NCHRP Report 350* TL-2 criteria, and to document the testing and the results of the testing in sufficient detail for FHWA consideration. The ultimate goal is to achieve FHWA approval of the NETC MELT as an approved TL-2 guardrail terminal." *NCHRP Report 350* Test Level 2 evaluates the impact performance of the guardrail terminal when impacted by a vehicle traveling 70 km/h (43.5 mi/h) rather than, as previously tested, the TL-3 impact speed of 100 km/h (62.2 mi/h).

NETC contracted to perform *NCHRP Report 350* test designations 2-30 and 2-31. *NCHRP Report 350* test designation 2-30 involves an 820-kg passenger car impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 0 degree with the quarter point of the vehicle aligned with the centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria. *NCHRP Report 350* test designation 2-31 involves a 2000-kg pickup truck impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 0 degree with the centerline of the vehicle aligned with the centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

Reported herein are the details of the NETC MELT installation, descriptions of the two full-scale crash tests performed, and the results and assessments of those tests.

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 construction of the NETC MELT (as shown in the adjacent photo) is along a wide out-of-service airfield apron. The apron consists of an unreinforced jointed concrete pavement in 3.8 m by 4.6 m blocks nominally 203-305 mm deep. The aprons and runways are about 50 years old and the joints have some displacement, but are otherwise flat and level.

Test Article – Design and Construction

The test installation consisted of 30.5 m (100 ft) of the steel post, routed wood blockout, W-beam (modified G4(1S)) guardrail system with a NETC MELT terminal installed on the impact end and a LET terminal on the downstream end, for a total installation length of 53.3 m (175 ft). A schematic of the test installation is shown in figure 1 and photographs of the test installation are shown in figure 2.

The modified G4(1S) guardrail system consisted of 1830 mm (6 ft) long, W150x13 (W6x8.5) steel posts with 356 mm (14 in) long routed offset blocks spaced 1905 mm (6 ft-3 in) on center. (NOTE: Most manufacturers are supplying W150x13 (W6x8.5) posts in place of the W150x14 (W6x9). Therefore, W150x13 (W6x8.5) posts were used as this would be the critical case.) The152 mm by 203 mm nominal (6 in by 8 in) routed wood blockouts and 3810 mm (12 ft-6 in) long 12-gauge W-beam rail elements were attached to the posts with 15.9-mm (5/8-in) diameter button head bolts without any washers. The height of the guardrail to the center of the W-beam rail element was 550 mm (21.7 in).

Drawings of the NETC MELT were provided by the Vermont Agency of Transportation. Figure 3 shows a schematic of the NETC MELT terminal as constructed and tested. Photographs of the terminal are shown in figure 4. The NETC MELT terminal had a total length of 11.4 m (37 ft-6 in), consisting of two 1905-mm (6 ft-3 in) spans at the beginning of the terminal, followed by six 1270-mm (4 ft-2 in) spans. This transitioned into the modified G4(1S) guardrail system. The height to the center of the W-beam rail element in the terminal section was 550 mm (21.7 in). The end of the terminal was flared 1220 mm (4 ft) from the tangent section of the

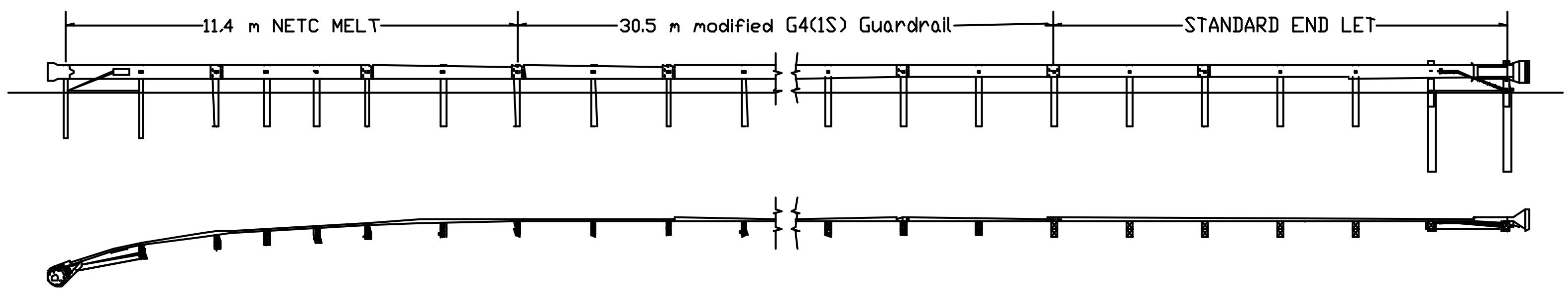


Figure 1. Layout of the NETC-MELT installation.

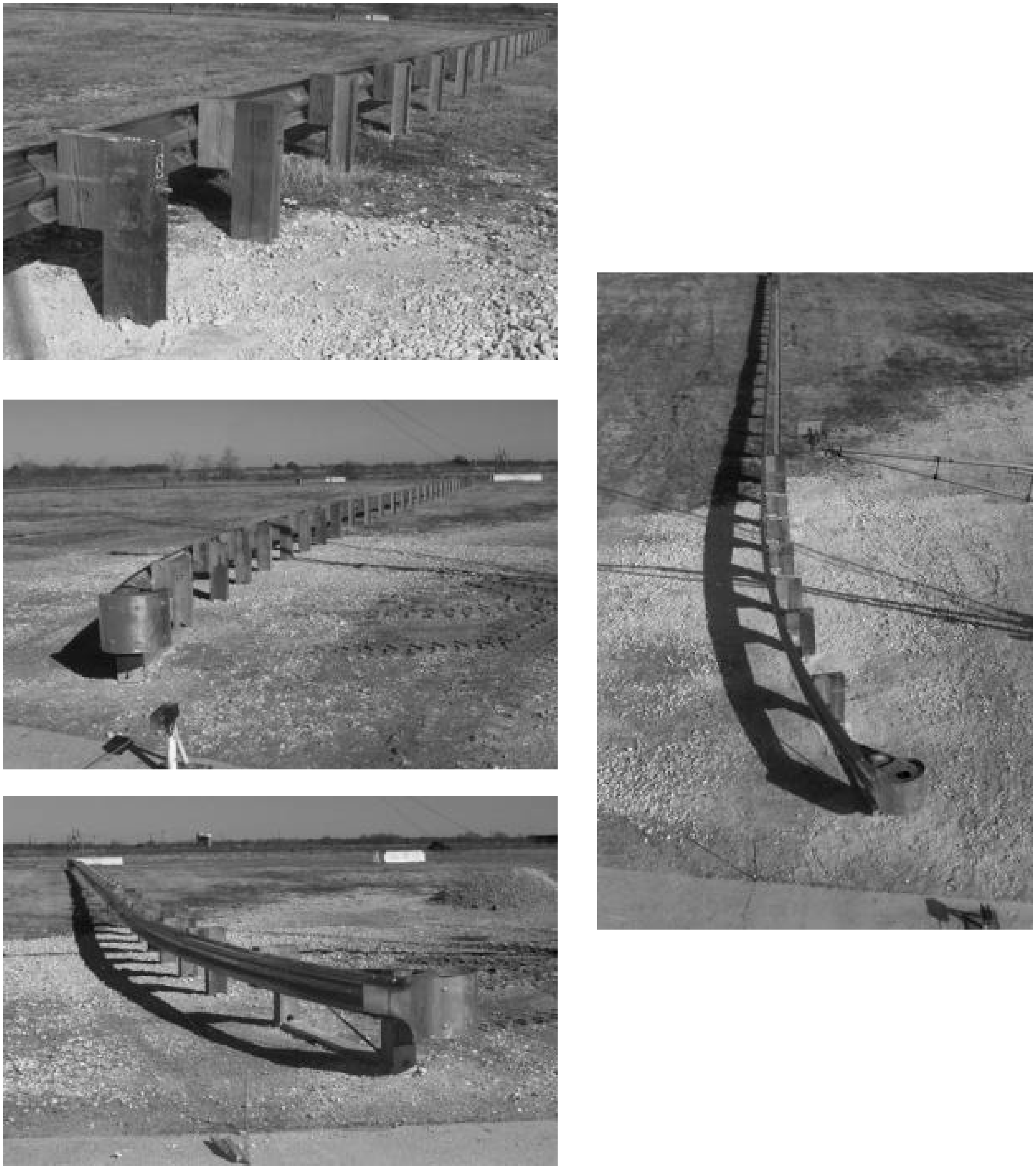


Figure 2. NETC-MELT installation prior to testing.

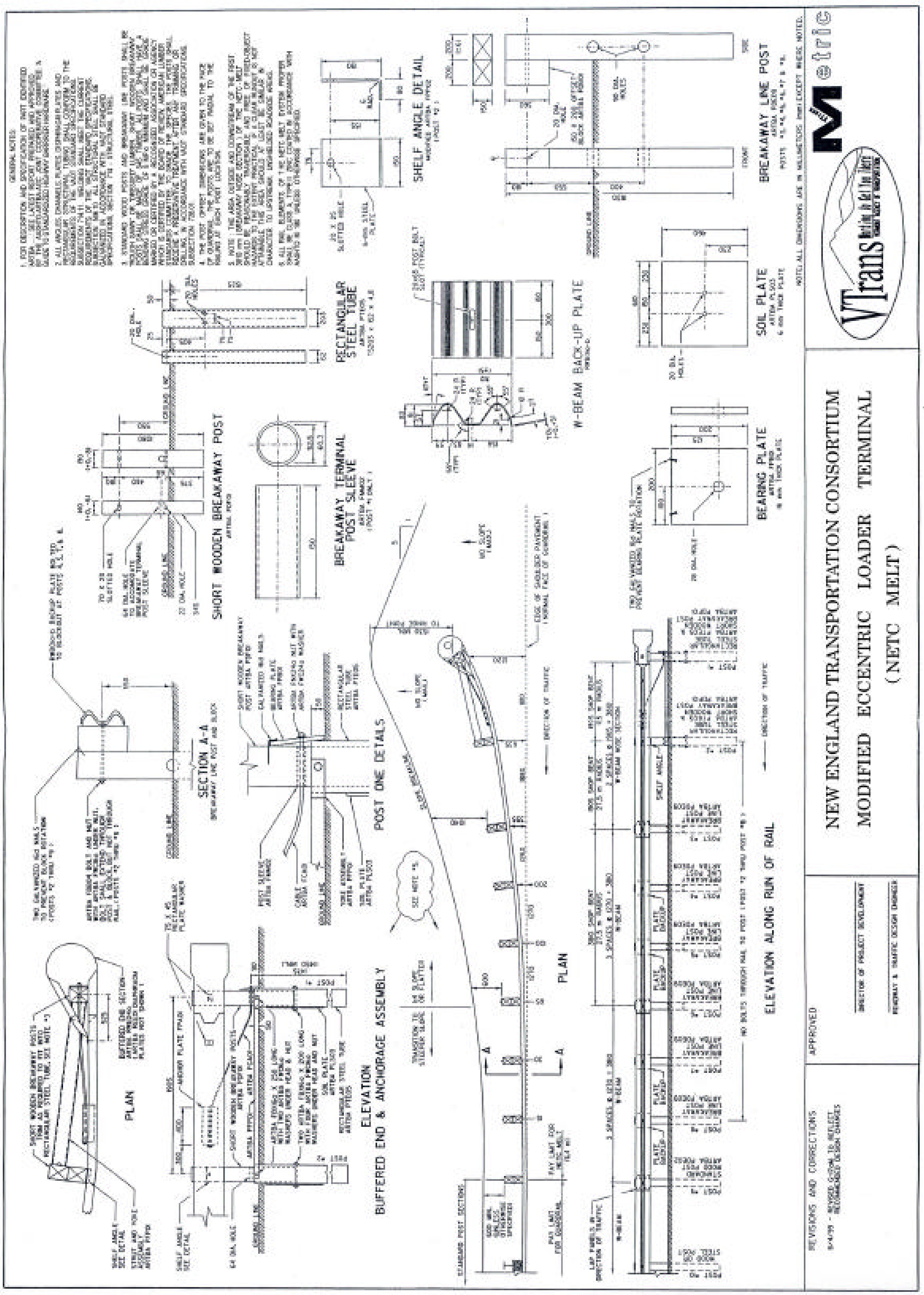


Figure 3. Details of the NETC-MELT.

Figure 4. NETC-MELT prior to testing.

guardrail and the flare was affected over the first 11.4 m (37 ft-6 in) with offsets of 1220, 635, 355, 200, 100, 65, 30, and 15 mm (4.0, 2.08, 1.16, 0.66, 0.33, 0.21, 0.1, and 0.05 ft) for posts 1 through 8, respectively. Note that the first 3810-mm (12 ft-6 in) section of the W-beam rail element for the end terminal was shop curved to a radius of 11.5 m (38 ft) over the first 1.9 m (6 ft-3 in) and to a radius of 27.m (90 ft) over the second 1.9 m (6 ft-3 in). The second 3810-mm (12 ft-6 in) section of the W-beam rail element for the end terminal was shop curved to a radius of 27.m (90 ft) over the entire length.

The buffered nosepiece had two bolt-on diaphragms. Posts 1 and 2 were breakaway wooden posts installed in 1525 mm (5 ft) long, TS 152 mm by 203 mm by 4.8 mm (TS 6 in by 8 in by 0.1875 in) steel foundation tubes with 460 mm by 610 mm by 6 mm (18 in by 24 in by 1/4 in) soil plates. A 160 mm by 50 mm (6 in by 2 in) channel strut connected the two foundation tubes at ground level for increased anchorage capacity. The posts were 1110 mm (43 in) long with cross-sectional dimensions of 140 mm by 190 mm (5-1/2 in by 7-1/2 in). A 64-mm (2 1/2-in) diameter hole was drilled through these posts at ground level to facilitate breaking of the posts upon impact. The second post (post 2) was not bolted to the W-beam rail element, but rested on a shelf angle attached to the post.

Posts 3 through 8 in the terminal section were 1830 mm (6 ft) long wooden breakaway line posts or Controlled Release Terminal (CRT) posts and the W-beam rail element was not bolted onto these posts. The W-beam rail element was bolted at the end post (post 1) and then the next bolted post was post 9 for an unsupported rail length of 11.4 m (37 ft-6 in). However, it should be noted that the rail element was supported by a shelf angle at the second post (post 2) and W-beam backup plates at posts 4, 5, 7, and 8. Although standard line spacing of 1905 mm (6 ft-3 in) started at post 9, the first standard line post began with post 10.

Test Conditions

According to *NCHRP Report 350*, a total of up to seven crash tests may be required for evaluation of a gating guardrail terminal under test level 2 (TL-2) conditions, which are listed as follows:

1. **NCHRP Report 350 test designation 2-30**: An 820-kg passenger car impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 0 degree with the quarter point of the vehicle aligned with the centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

2. **NCHRP Report 350 test designation 2-31**: A 2000-kg pickup truck impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 0 degree with the centerline of the vehicle aligned with the centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

3. **NCHRP Report 350 test designation 2-32**: An 820-kg passenger car impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 15 degrees with the centerline of the vehicle aligned with the

centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

4. **NCHRP Report 350 test designation 2-33**: A 2000-kg pickup truck impacting the terminal end-on at a nominal impact speed and angle of 70 km/h and 15 degrees with the centerline of the vehicle aligned with the centerline of the nose (i.e., end post) of the terminal. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

5. **NCHRP Report 350 test designation 2-34**: An 820-kg passenger car impacting the terminal at a nominal impact speed and angle of 100 km/h and 15 degrees mid-point between the end of the terminal and the beginning of the length-of-need. This test is intended primarily to evaluate occupant risk and vehicle trajectory criteria.

6. **NCHRP Report 350 test designation 2-35**: A 2000-kg pickup truck impacting the terminal at a nominal impact speed and angle of 70 km/h and 20 degrees at the beginning of the length-of-need. This structural adequacy test is intended to evaluate the ability of the device to contain and redirect the 2000-kg vehicle.

7. **NCHRP Report 350 test designation 2-39**: A 2000-kg pickup truck impacting the terminal at a nominal impact speed and angle of 70 km/h and 20 degrees mid-point between the nose and the end of the terminal in the reverse direction. This test is intended to evaluate the performance of a terminal for a "reverse" hit.

NETC contracted to perform *NCHRP Report 350* test designations 2-30 and 2-31. These two tests are reported herein.

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 tests were 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.

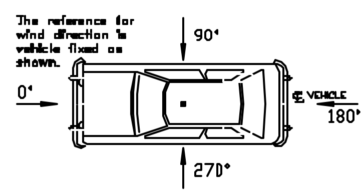
CRASH TEST 400401-1 (*NCHRP REPORT 350* TEST NO. 2-30)

Test Vehicle

A 1998 Geo Metro, shown in figures 5 and 6, was used for the first crash test. Test inertia weight of the vehicle was 820 kg, and its gross static weight was 896 kg. The height to the lower edge of the vehicle front bumper was 400 mm, and the height to the upper edge of the front bumper was 525 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 19. 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 February 15, 2002. Rainfall of 29 mm was recorded ten days prior to the test. No other rainfall was recorded for the remaining ten days prior to the date of the test. Moisture content of the *NCHRP Report 350* standard soil in which the NETC MELT was installed was 7.6 percent, 6.2 percent, and 6.9 percent at posts 1, 2, and 3, respectively. Weather conditions at the time of testing were as follows: Wind Speed: 13 km/h; Wind Direction: 270 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); Temperature: 16 °C; Relative Humidity: 74 percent.



Impact Description

The 896-kg vehicle, traveling at a speed of 71.5 km/h, impacted the nose of the NETC MELT at 0.6 degrees counterclockwise to the tangent of the length-of-need. The right front quarter point of the vehicle was aligned with the centerline of post 1.

At approximately 0.027 s after impact, post 1 began to move and, at 0.030 s, the rail element at post 3 moved toward traffic lanes. The rail element moved away (toward traffic lanes) from posts 4, 2, 5, and 6 at 0.034 s, 0.041 s, 0.048 s, and 0.050 s, respectively. The vehicle began to redirect at 0.059 s. At 0.088 s, post 1 fractured at ground level and, at 0.093 s and 0.109 s, respectively, the rail element at posts 7 and 8 moved toward traffic lanes. The first elbow (at 490 mm from the beginning of the rail element) formed at 0.113 s, and the second elbow (2040 mm from the beginning of the rail element) formed at 0.115 s. At 0.142 s, post 2 began to move and, at 0.192 s, the third elbow (at 1310 mm from the center of the first rail splice) formed. Post 2 fractured at ground level at 0.195 s and post 3 began to move at 0.295 s. At 0.357 s, post 3 fractured at ground level and, at 0.411 s, the blockout at post 3 separated from the post and rail element. Post 4 moved at 0.0446 s and then fractured at ground level at 0.480 s. At 0.692 s, the third elbow contacted the lower frame rail of the vehicle, at which time the vehicle was traveling at a speed of 23.3 km/h.

Figure 5. Vehicle/installation geometrics for test 400401-1.

Figure 6. Vehicle before test 400401-1.

At 0.983 s, the vehicle lost contact with the rail element and was traveling at a speed of 15.5 km/h and an exit angle of 37.6 degrees clockwise to the tangent of the length of need. Brakes on the vehicle were not applied. At 2.975 s, the vehicle subsequently came to rest 4.58 m behind post 6 and 7 (7.75 m downstream of impact) and was oriented at 62.3 degrees clockwise of the tangent of the length of need. Sequential photographs of the test period are shown in appendix C, figures 21 and 22.

Damage to Test Article

Posts 1 through 4 fractured at ground level as shown in figures 7 and 8. Most of the pieces followed along the vehicle path or were thrown behind the terminal. One piece came to rest 3.05 m forward of the face of the rail between posts 14 and 15. The ground strut on the upstream end moved 10 mm and no movement was noted on the downstream terminal. Three elbows formed in the terminal: one 490 mm from the beginning of the rail element, a second 2040 mm from the beginning of the rail element, and a third 1310 mm from the center of the first splice. Maximum deflection of the rail element toward traffic lanes was 1.78 m and maximum deformation occurred over a distance of 3.25 m. Working width was 5.08 m.

Vehicle Damage

The vehicle sustained damage to the front as shown in figure 9. Structural damage was imparted to the right front strut, right front mount, and right front axle, and the firewall and floor pan were deformed. Also damaged were the front bumper, hood, fan, radiator, radiator support, right and left front quarter panels, left front tire and wheel rim, and the left rear tire. The right door was jammed and the windshield sustained stress cracking. Maximum exterior crush to the vehicle was 400 mm at the right front quarter point near bumper height. Maximum occupant compartment deformation was 37 mm just to the right of the center firewall area. Photographs of the interior of the vehicle are shown in figure 10. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 3 and 4.

Occupant Risk Factors

Data from the accelerometer, located at the vehicle c.g., were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 6.3 m/s at 0.154 s, the highest 0.010-s occupant ridedown acceleration was –8.4 g's from 0.165 to 0.175 s, and the maximum 0.050-s average acceleration was –9.3 g's between 0.019 and 0.069 s. In the lateral direction, the occupant impact velocity was 1.0 m/s at 0.154 s, the highest 0.010-s occupant ridedown acceleration was 3.6 g's from 0.703 to 0.713 s, and the maximum 0.050-s average was 3.1 g's between 0.693 and 0.743 s. These data and other pertinent information from the test are summarized in figure 11. Vehicle angular displacements and accelerations versus time traces are presented in appendix D, figures 25 through 31.

Figure 7. Vehicle trajectory after test 400401-1.

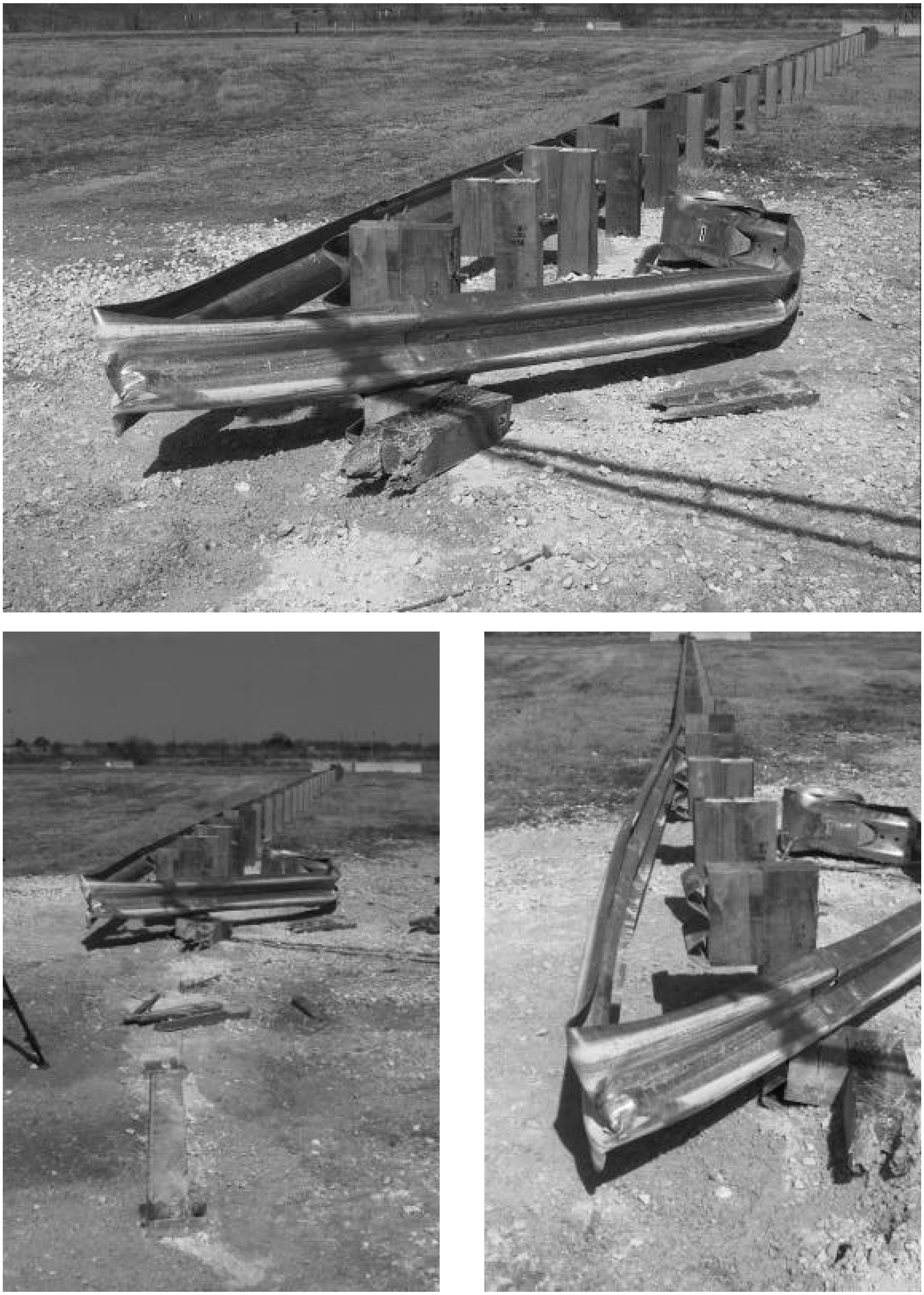


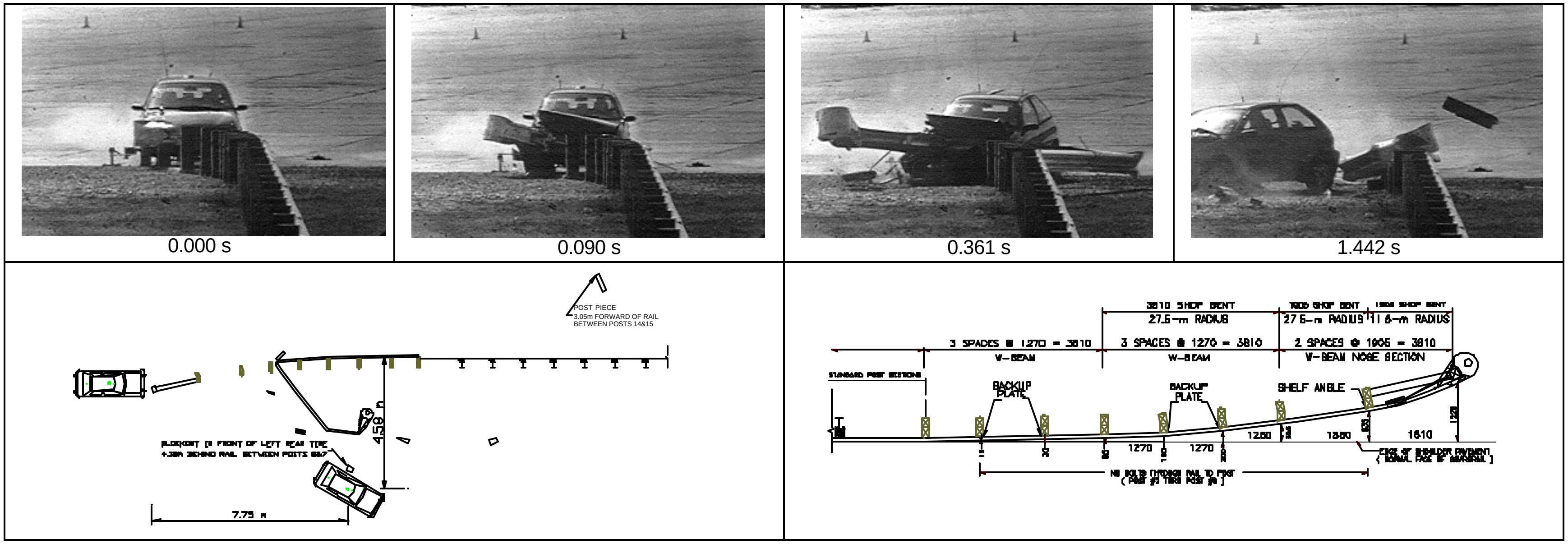
Figure 8. Installation after test 400401-1.

Figure 9. Vehicle after test 400401-1.

Before Test

After Test

Figure 10. Interior of vehicle for test 400401-1.



General Information
- Test Agency: Texas Transportation Institute
- Test No.: 400401-1
- Date: 02/15/02

Test Article
- Type: Terminal
- Name: Modified Eccentric Loader Terminal
- Installation Length (m): 53.3
- Material or Key Elements: Mod. G4(1S) W-Beam Guardrail With NETC Mod. Eccentric Loader Terminal

Soil Type and Condition: Standard Soil, Dry

Test Vehicle
- Type: Production
- Designation: 820C
- Model: 1998 Geo Metro
- Mass (kg)
  - Curb: 799
  - Test Inertial: 820
  - Dummy: 76
  - Gross Static: 896

Impact Conditions
- Speed (km/h): 71.5
- Angle (deg): 0.6

Exit Conditions
- Speed (km/h): 15.5
- Angle (deg): 37.6

Occupant Risk Values
- Impact Velocity (m/s)
  - x-direction: 6.3
  - y-direction: 1.0
- THIV (km/h): 22.7
- Ridedown Accelerations (g's)
  - x-direction: -8.4
  - y-direction: 3.6
- PHD (g's): 8.5
- ASI: 0.81
- Max. 0.050-s Average (g's)
  - x-direction: -9.3
  - y-direction: 3.1
  - z-direction: -2.5

Test Article Deflections (m)
- Dynamic: 3.25
- Permanent: 3.25
- Working Width: 5.08

Vehicle Damage
- Exterior
  - VDS: 12FC3
  - CDC: 12FDEW3
- Maximum Exterior
  - Vehicle Crush (mm): 400
- Interior
  - OCDI: FS0011000
- Max. Occ. Compart.
  - Deformation (mm): 37

Post-Impact Behavior
- (during 1.0 s after impact)
- Max. Yaw Angle (deg): 41.5
- Max. Pitch Angle (deg): -5.9
- Max. Roll Angle (deg): -6.1

Figure 11. Summary of results for test 400401-1, *NCHRP Report 350* test 2-30.

Assessment of Test Results

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

- **Structural Adequacy**

  C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.

  Results: The NETC MELT allowed the 820C vehicle to gate through the terminal and come to a controlled stop behind the installation.

- **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: Posts 1 through 4 fractured at ground level but did not penetrate nor show potential for penetrating the occupant compartment. Most of the pieces of the fractured posts followed along with the vehicle or were thrown behind the installation. Maximum occupant compartment deformation was 37 mm in the center front firewall area.

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

  Results: The vehicle remained upright during and after the collision period.

  H. Occupant impact velocities should satisfy the following:

  Longitudinal and Lateral Occupant Impact Velocity – m/s

Preferred	*Maximum*
9	*12*

  Results: Longitudinal occupant impact velocity was 6.3 m/s and lateral occupant impact velocity was 1.0 m/s.

  I. Occupant ridedown accelerations should satisfy the following:

  Longitudinal and Lateral Occupant Ridedown Accelerations – g's

Preferred	*Maximum*
15	*20*

  Results: Longitudinal ridedown acceleration was –8.4 g's and lateral ridedown acceleration was 3.6 g's.

- **Vehicle Trajectory**

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

  Results: The vehicle did not intrude into adjacent traffic lanes.

  N. Vehicle trajectory behind the test article is acceptable.

  Results: The vehicle came to rest behind the terminal.

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**

  Most of the fractured posts and blockouts followed along the vehicle path or were thrown behind the terminal. One piece came to rest 3.05 m forward of the face of the rail between posts 14 and 15

- **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 (stress)
     - 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

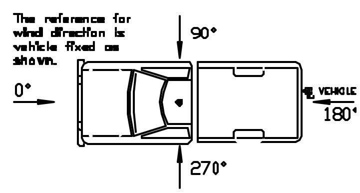
CRASH TEST 400401-2 (*NCHRP REPORT 350* TEST NO. 2-31)

Test Vehicle

A 1997 Chevrolet 2500 pickup truck, shown in figures 12 and 13, was used for the crash test. Test inertia weight of the vehicle was 2044 kg, and its gross static weight was 2044 kg. The height to the lower edge of the vehicle front bumper was 435 mm, and the height to the upper edge of the front bumper was 655 mm. Additional dimensions and information on the vehicle are given in appendix B, figure 20. 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 February 20, 2002. Rainfall of 7 mm was recorded one day prior to the test. No other rainfall was recorded for the remaining ten days prior to the date of the test. Moisture content of the *NCHRP Report 350* standard soil in which the NETC MELT was installed was 9.2 percent. Weather conditions at the time of testing were as follows: Wind Speed: 7 km/h; Wind Direction: 270 degrees with respect to the vehicle (vehicle was traveling in a northerly direction); Temperature: 18 °C; Relative Humidity: 50 percent.



Impact Description

The 2044-kg vehicle, traveling at a speed of 71.6 km/h, impacted the nose of the NETC MELT at 0.2 degrees to the tangent of the length-of-need. The centerline of the vehicle was aligned with the centerline of post 1.

At approximately 0.015 s after impact, the rail element at post 2 began to deflect toward traffic lanes and, at 0.017 s, the first elbow (at 380 mm from the beginning of the rail element) began to form. Post 2 moved at 0.018 s and the rail element at post 3 began to deflect toward traffic lanes at 0.019 s. The rail element began to move away from posts 6, 4, and 5 (toward traffic lanes) at 0.025 s, 0.027 s, and 0.038 s, respectively. At 0.060 s, post 1 fractured at ground level and, at 0.073 s, the second elbow (at 1730 mm from the beginning of the rail element) began to form. The buffer end of the terminal contacted post 2 at 0.086 s and post 2 moved at 0.096 s. The rail element began to move away from posts 7 and 8 (toward traffic lanes) at 0.098 s and 0.114 s, respectively. At 0.128 s, the vehicle began to redirect and, at 0.166 s, post 2 fractured at ground level. The left front tire contacted post 3 at 0.278 s and the post fractured at ground level at 0.298 s. The left front tire contacted post 4 at 0.370 s and post 9 moved at 0.501 s.

Figure 12. Vehicle/installation geometrics for test 400401-2.

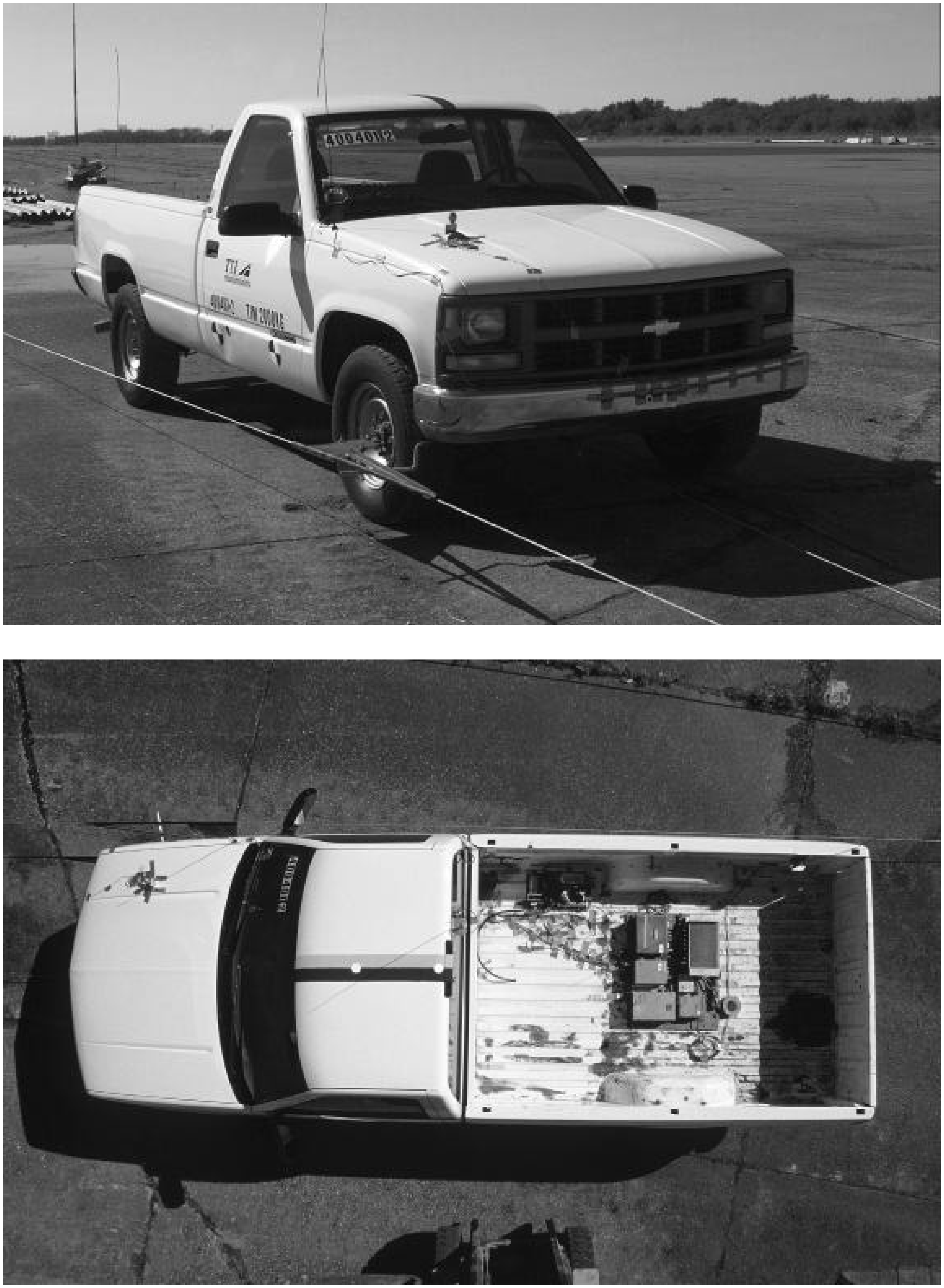


Figure 13. Vehicle before test 400401-2.

At 0.591 s, the vehicle lost contact with the rail element at 0.591 s, and was traveling at a speed of 53.8 km/h and an exit angle of 2.2 degrees. Brakes on the vehicle were not applied. As the vehicle continued forward motion, it contacted the rear of post 18 at 1.544 s. The vehicle subsequently came to rest on top of the rail element at post 21 (34.3 m downstream of impact). Sequential photographs of the test period are shown in appendix C, figures 23 and 24.

Damage to Test Article

Posts 1 through 3 fractured at ground level, as shown in figures 14 through 15. Post 1 remained in the buffer head of the terminal and all other debris traveled along the vehicle path. Two elbows formed in the rail element: one 380 mm from the beginning of the rail element and the second 1730 mm from the beginning. The upstream ground strut moved 17 mm and no movement was noted in the downstream terminal. Posts 14 through 20 were rotated from the secondary impact.

Vehicle Damage

Damage to the vehicle was restricted to the front of the vehicle, as shown in figure 16. The stabilizer bar and the left and right front of the frame were deformed. Also damaged were the front bumper, fan, and radiator. Maximum exterior crush to the vehicle was 340 mm at the center front at bumper height. No deformation of the occupant compartment occurred. Photographs of the interior of the vehicle are shown in figure 17. Exterior vehicle crush and occupant compartment measurements are shown in appendix B, tables 5 and 6.

Occupant Risk Factors

Data from the triaxial accelerometer, located at the vehicle c.g., were digitized to compute occupant impact velocity and ridedown accelerations. In the longitudinal direction, occupant impact velocity was 4.2 m/s at 0.244 s, maximum 0.010-s ridedown acceleration was –3.7 g's from 0.509 to 0.519 s, and the maximum 0.050-s average was –3.7 g's between 0.025 and 0.075 s. In the lateral direction, the occupant impact velocity was 1.0 m/s at 0.244 s, the highest 0.010-s occupant ridedown acceleration was 3.6 g's from 0.350 to 0.360 s, and the maximum 0.050-s average was 1.9 g's between 0.018 and 0.068 s. These data and other information pertinent to the test are presented in figure 18. Vehicle angular displacements and accelerations versus time traces are shown in appendix D, figures 32 through 38.

Figure 14. Vehicle trajectory after test 400401-2.

Figure 15. Installation after test 400401-2.

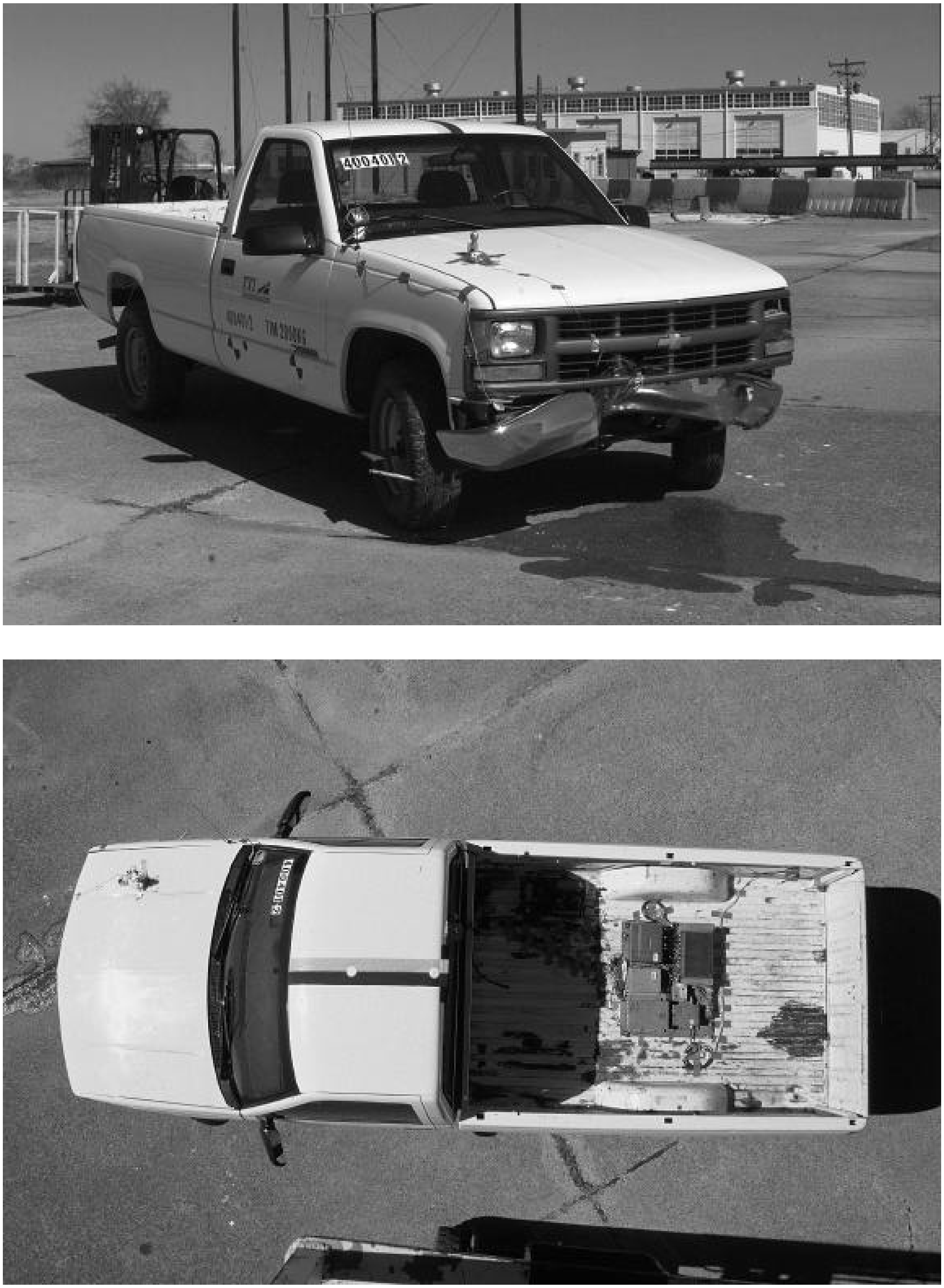
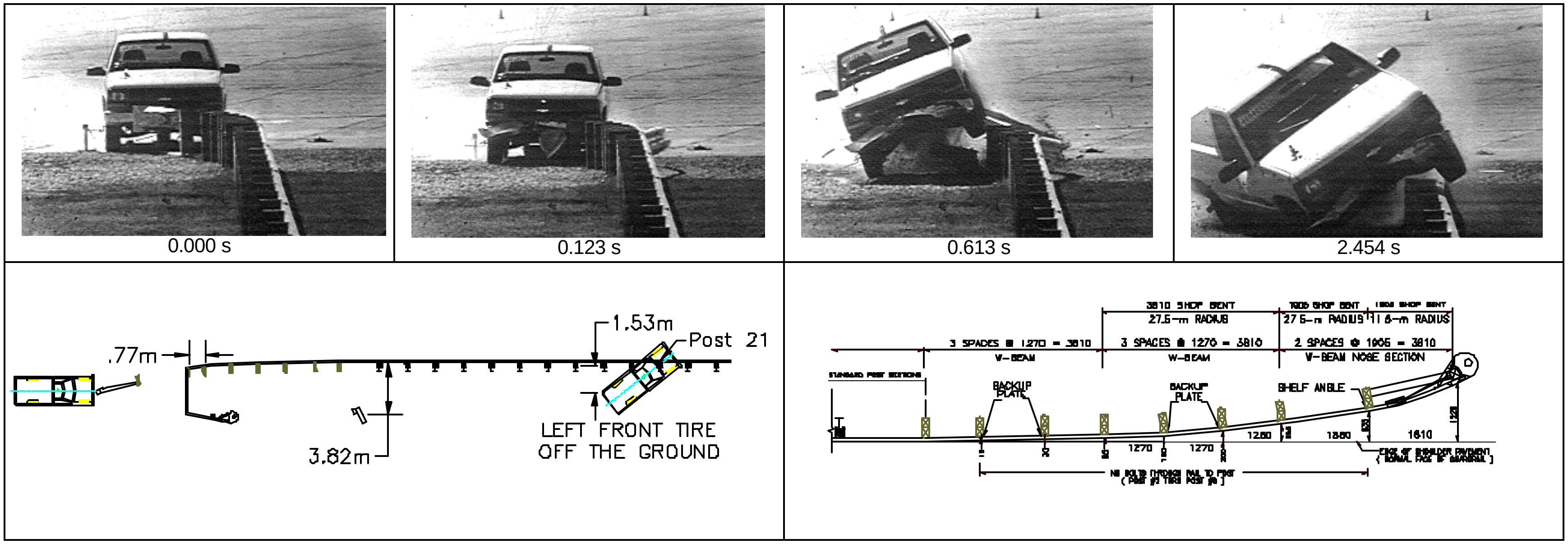


Figure 16. Vehicle after test 400401-2.

Before Test

After Test

Figure 17. Interior of vehicle for test 400401-2.



General Information

Test Agency	Texas Transportation Institute
Test No.	400401-2
Date	02/20/02

Test Article

Type	Terminal
Name	Modified Eccentric Loader Terminal
Installation Length (m)	53.3
Material or Key Elements	Mod. G4(1S) W-Beam Guardrail With NETC Mod. Eccentric Loader Terminal
Soil Type and Condition	Standard Soil, Dry

Test Vehicle

Type	Production
Designation	2000P
Model	1997 Chevrolet 2500 Pickup Truck
Mass (kg)	
Curb	2159
Test Inertial	2044
Dummy	N/A
Gross Static	2044

Impact Conditions

Speed (km/h)	71.6
Angle (deg)	0.2

Exit Conditions

Speed (km/h)	53.8
Angle (deg)	2.2

Occupant Risk Values

Impact Velocity (m/s)	
x-direction	4.2
y-direction	1.0
THIV (km/h)	15.3
Ridedown Accelerations (g's)	
x-direction	-3.7
y-direction	3.6
PHD (g's)	4.2
ASI	0.38
Max. 0.050-s Average (g's)	
x-direction	-3.7
y-direction	1.9
z-direction	-3.1

Test Article Deflections (m)

Dynamic	0.71
Permanent	0.71
Working Width	4.08

Vehicle Damage

Exterior	
VDS	12FC2
CDC	12FCEW2
Maximum Exterior Vehicle Crush (mm)	340
Interior	
OCDI	FS0000000
Max. Occ. Compart. Deformation (mm)	None

Post-Impact Behavior

(during 1.0 s after impact)	
Max. Yaw Angle (deg)	-14.8
Max. Pitch Angle (deg)	-11.3
Max. Roll Angle (deg)	24.9

Figure 18. Summary of results for test 400401-2, *NCHRP Report 350* test 2-31.

Assessment of Test Results

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

- **Structural Adequacy**

  C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.

  Results: The NETC MELT allowed the 2000P vehicle to gate through the terminal.

- **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: Posts 1 through 3 fractured at ground level but did not penetrate nor show potential for penetrating the occupant compartment. All of the pieces of the fractured posts followed along with the vehicle. No deformation of the occupant compartment occurred.

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

  Results: The vehicle remained upright during and after the collision period.

  H. Occupant impact velocities should satisfy the following:

Longitudinal and Lateral Occupant Impact Velocity – m/s	
Preferred	*Maximum*
9	*12*

  Results: Longitudinal occupant impact velocity was 4.2 m/s and lateral occupant impact velocity was 1.0 m/s.

  I. Occupant ridedown accelerations should satisfy the following:

Longitudinal and Lateral Occupant Ridedown Accelerations – g's	
Preferred	*Maximum*
15	*20*

  Results: Longitudinal ridedown acceleration was –3.7 g's and lateral ridedown acceleration was 3.6 g's.

♦ **Vehicle Trajectory**

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

<u>Results</u>: The vehicle did not intrude into adjacent traffic lanes as it came to rest behind and atop the installation.

N. Vehicle trajectory behind the test article is acceptable.

<u>Results</u>: The vehicle came to rest behind the installation.

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

- <u>a. No windshield contact</u>
- 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 <u>yes</u> or no

♦ **Loss of Vehicle Control**

1. Physical loss of control

2. Loss of windshield visibility

3. Perceived threat to other vehicles

<u>**4. Debris on pavement**</u>

♦ **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

The fractured posts followed along with the vehicle and did not pose any more of a threat than the vehicle.

♦ **Vehicle and Device Condition**

1. Vehicle Damage

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

2. Windshield Damage

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

SUMMARY AND CONCLUSIONS

SUMMARY OF FINDINGS

NCHRP Report 350 Test 2-30

The NETC MELT allowed the 820C vehicle to gate through the terminal and come to a controlled stop behind the installation. Posts 1 through 4 fractured at ground level but did not penetrate nor show potential for penetrating the occupant compartment. Most of the pieces of the fractured posts followed along with the vehicle or were thrown behind the installation. Maximum occupant compartment deformation was 37 mm in the center front firewall area. The vehicle remained upright during and after the collision period. Longitudinal occupant impact velocity was 6.3 m/s and lateral occupant impact velocity was 1.0 m/s. Longitudinal ridedown acceleration was –8.4 g's and lateral ridedown acceleration was 3.6 g's. The vehicle did not intrude into adjacent traffic lanes as it came to rest behind the terminal.

NCHRP Report 350 Test 2-31

The NETC MELT allowed the 2000P vehicle to gate through the terminal. Posts 1 through 3 fractured at ground level but did not penetrate nor show potential for penetrating the occupant compartment. All of the pieces of the fractured posts followed along with the vehicle. No deformation of the occupant compartment occurred. The vehicle remained upright during and after the collision period. Longitudinal occupant impact velocity was 4.2 m/s and lateral occupant impact velocity was 1.0 m/s. Longitudinal ridedown acceleration was –3.7 g's and lateral ridedown acceleration was 3.6 g's. The vehicle did not intrude into adjacent traffic lanes as it came to rest behind and atop the installation.

CONCLUSIONS

As shown in tables 1 and 2, the NETC MELT met the required criteria for *NCHRP Report 350* test designations 2-30 and 2-31.

Table 1. Performance evaluation summary for test 400401-1, *NCHRP Report 350* test 2-30.

Test Agency: Texas Transportation Institute | Test No.: 400401-1 | Test Date: 02/15/2002

<table>
<tr><th>NCHRP Report 350 Evaluation Criteria</th><th>Test Results</th><th>Assessment</th></tr>
<tr><td><u>Structural Adequacy</u></td><td></td><td></td></tr>
<tr><td>C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.</td><td>The NETC MELT allowed the 820C vehicle to gate through the terminal and come to a controlled stop behind the installation.</td><td>Pass</td></tr>
<tr><td><u>Occupant Risk</u>
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.</td><td>Posts 1 through 4 fractured at ground level but did not penetrate nor show potential for penetrating the occupant compartment. Most of the pieces of the fractured posts followed along with the vehicle or were thrown behind the installation. Maximum occupant compartment deformation was 37 mm in the center front firewall area.</td><td>Pass</td></tr>
<tr><td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td><td>The vehicle remained upright during and after the collision period.</td><td>Pass</td></tr>
<tr><td>H. Occupant impact velocities should satisfy the following:<table><tr><th colspan="3">Occupant Velocity Limits (m/s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and lateral</td><td>9</td><td>12</td></tr></table></td><td>Longitudinal occupant impact velocity was 6.3 m/s and lateral occupant impact velocity was 1.0 m/s.</td><td>Pass</td></tr>
<tr><td>I. Occupant ridedown accelerations should satisfy the following:<table><tr><th colspan="3">Occupant Ridedown Acceleration Limits (g’s)</th></tr><tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr><tr><td>Longitudinal and lateral</td><td>15</td><td>20</td></tr></table></td><td>Longitudinal ridedown acceleration was –8.4 g’s and lateral ridedown acceleration was 3.6 g’s.</td><td>Pass</td></tr>
<tr><td><u>Vehicle Trajectory</u>
K. After collision, it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td><td>The vehicle did not intrude into adjacent traffic lanes.</td><td>Pass*</td></tr>
<tr><td>N. Vehicle trajectory behind the test article is acceptable.</td><td>The vehicle came to rest behind the terminal.</td><td>Pass</td></tr>
</table>

*Criterion K is preferable, not required.

Table 2. Performance evaluation summary for test 400401-2, *NCHRP Report 350* test 2-31.

Test Agency: Texas Transportation Institute | Test No.: 400401-2 | Test Date: 02/20/2002

***NCHRP Report 350* Evaluation Criteria**	**Test Results**	**Assessment**
Structural Adequacy		
C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	The NETC MELT allowed the 2000P vehicle to gate through the terminal.	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.	Posts 1 through 3 fractured at ground level but did not penetrate nor show potential for penetrating the occupant compartment. All of the pieces of the fractured posts followed along with the vehicle. No deformation of the occupant compartment occurred.	Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright during and after the collision period.	Pass
H. Occupant impact velocities should satisfy the following: Occupant Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Longitudinal occupant impact velocity was 4.2 m/s and lateral occupant impact velocity was 1.0 m/s.	Pass
I. Occupant ridedown accelerations should satisfy the following: Occupant Ridedown Acceleration Limits (g's) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Longitudinal ridedown acceleration was –3.7 g's and lateral ridedown acceleration was 3.6 g's.	Pass
Vehicle Trajectory		
K. After collision, it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes as it came to rest behind the installation.	Pass*
N. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest behind the installation.	Pass

*Criterion K is preferable, not required.

APPENDIX A. CRASH TEST PROCEDURES AND DATA ANALYSIS

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

ELECTRONIC INSTRUMENTATION AND DATA PROCESSING

The test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch, and yaw rates; a triaxial accelerometer near the vehicle center of gravity (c.g.) to measure longitudinal, lateral, and vertical acceleration levels; and a back-up biaxial accelerometer in the rear of the vehicle to measure longitudinal and lateral acceleration levels. These accelerometers were ENDEVCO Model 2262CA, piezoresistive accelerometers with a ±100 g range.

The accelerometers are strain gage type with a linear millivolt output proportional to acceleration. Angular rate transducers are solid state, gas flow units designed for high-"g" service. Signal conditioners and amplifiers in the test vehicle increase the low level signals to a ±2.5 volt maximum level. The signal conditioners also provide the capability of an R-Cal or shunt calibration for the accelerometers and a precision voltage calibration for the rate transducers. The electronic signals from the accelerometers and rate transducers are transmitted to a base station by means of a 15 channel, constant bandwidth, Inter-Range Instrumentation Group (I.R.I.G.), FM/FM telemetry link for recording on magnetic tape and for display on a real-time strip chart. Calibration signals from the test vehicle are recorded before the test and immediately afterwards. A crystal controlled time reference signal is simultaneously recorded with the data. Pressure-sensitive switches on the bumper of the impacting vehicle are actuated prior to impact by wooden dowels to indicate the elapsed time over a known distance to provide a measurement of impact velocity. The initial contact also produces and "event" mark on the data record to establish the instant of contact with the installation.

The multiplex of data channels, transmitted on one radio frequency, is received and demultiplexed onto separate tracks of a 28 track (I.R.I.G.) tape recorder. After the test, the data are played back from the tape machine and digitized. A proprietary software program (WinDigit) converts the analog data from each transducer into engineering units using the R0cal and pre-zero valued at 10,000 samples per second per channel. WinDigit also provides SAE J211 class 180 phaseless digital filtering and vehicle impact velocity.

All accelerometers are calibrated annually according to SAE J211 Mar95 *4.6.1* by means of an ENDEVCO 2901, precision primary vibration standard. This device and its support instruments are returned to the factory annually for a National Institute of Standards Technology (NIST) traceable calibration. The subsystems of each data channel are also evaluated annually, using instruments with current NIST traceability, and the results factored into the accuracy of the total data channel, per SAE J211. Calibrations and evaluations are made any time data is suspect.

The Test Risk Assessment Program (TRAP) used 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 give impulse period. In addition, maximum average accelerations over 50-ms intervals in each of the three directions are computed. For reporting purposes, the data from the vehicle-mounted accelerometers are filtered with a 60-Hz digital filter and acceleration versus time curves for the longitudinal, lateral, and vertical directions are plotted using TRAP.

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

ANTHORPOMORPHIC DUMMY INSTRUMENTATION

An Alderson Research Laboratories Hybrid II, 50^{th} percentile male anthropomorphic dummy, restrained with lap and shoulder belts, was placed in the driver's position of the 820C vehicle. The dummy was uninstrumented. Use of a dummy in the 2000P vehicle is optional according to *NCHRP Report 350* and there was no dummy used in the test 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 is positioned on the impacting vehicle to indicate the instant of contact with the installation and is visible from each camera. The films from these high-speed cameras were analyzed on a computer-linked Motion Analyzer to observe phenomena occurring during the collision and to obtain event time, displacement, and angular data. A BetaCam, a VHS-format video camera, and still cameras were used to document conditions of the test vehicle and installation before and after the test.

TEST VEHICLE PROPULSION AND GUIDANCE

The test vehicle was towed into the test installation using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicle is tensioned along the path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. An additional steel cable is connected to the test vehicle, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground so the tow vehicle moves away from the test site. A two-to-one speed ratio between the test and tow vehicle exists with this system. Just prior to impact with the installation, the test vehicle was released to be free-wheeling and unrestrained. The vehicle remains free-wheeling, i.e., no steering or braking inputs, until the vehicle clears the immediate area of the test sits, at which time brakes on the vehicle are activated bringing it to a safe and controlled stop.

APPENDIX B. TEST VEHICLE PROPERTIES AND INFORMATION

DATE 02/15/02 TEST NO.: 400401-1 VIN NO. 2C1MR2266W6717228

YEAR 1998 MAKE: Geo MODEL: Metro

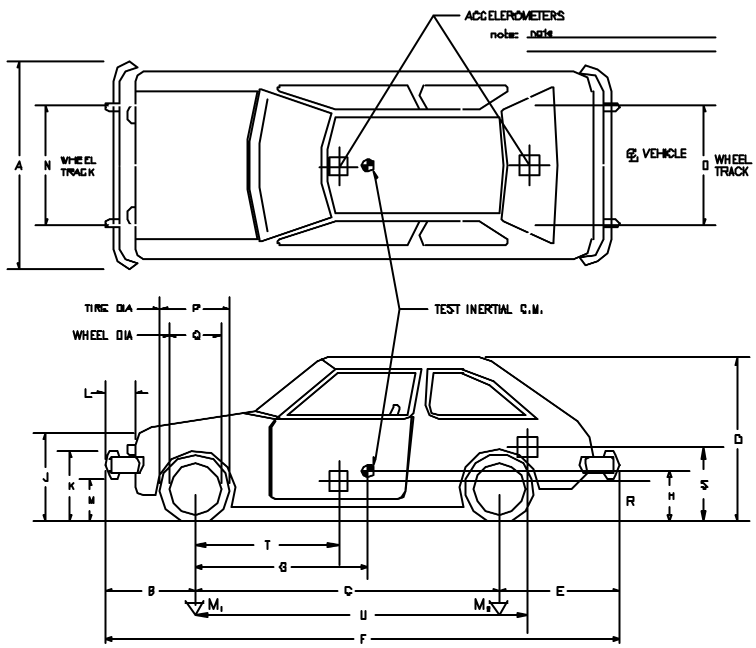
TIRE INFLATION PRESSURE: ODOMETER: 107147 TIRE SIZE: 155 80 R13

1st Use: 2nd or More Use: Minor Damage Charged to Project:

MASS DISTRIBUTION (kg) LF 255 RF 251 LR 155 RR 159

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

XXX



ENGINE TYPE: 3 CYL

ENGINE CID: 1.0 L

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: 50th percentile male

MASS: 76 kg

SEAT POSITION: driver

GEOMETRY – (mm)

A	1470	E	560	J	610	N	1390	R	400
B	770	F	3695	K	525	O	1375	S	570
C	2365	G	905.6	L	170	P	570	T	930
D	1430	H		M	400	Q	365	U	2500

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	493	506	542
M_2	306	314	354
M_T	799	820	896

Figure 19. Vehicle properties for test 400401-1.

Table 3. Exterior crush measurements for test 400401-1.

VEHICLE CRUSH MEASUREMENT SHEET[1]

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

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

Specific Impact Number	Plane* of C-Measurements	Direct Damage		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front bumper	800	400	1380	50	110	210	290	310	400	0

[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).

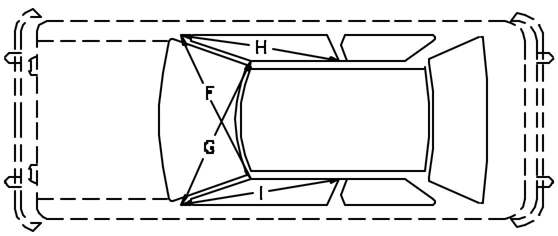
***Measure and document on the vehicle diagram the location of the maximum crush.

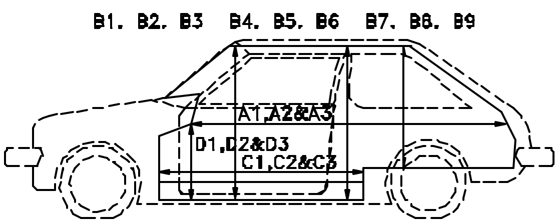
Note: Use as many lines/columns as necessary to describe each damage profile.

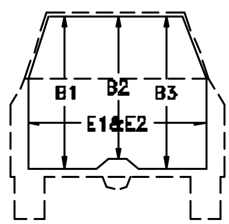
Table 4. Occupant compartment measurements for test 400401-1.

Small Car

Occupant Compartment Deformation







	BEFORE	AFTER
A1	1430	1430
A2	2005	2005
A3	1435	1435
B1	967	967
B2	920	924
B3	1002	1015
B4	930	930
B5	907	907
B6	938	938
B7		
B8		
B9		
C1	561	555
C2	695	658
C3	560	540
D1	246	230
D2	142	142
D3	246	260
E1	1217	1222
E2	1177	1175
F	1210	1210
G	1210	1210
H	900	900
I	900	900
J	1187	1195

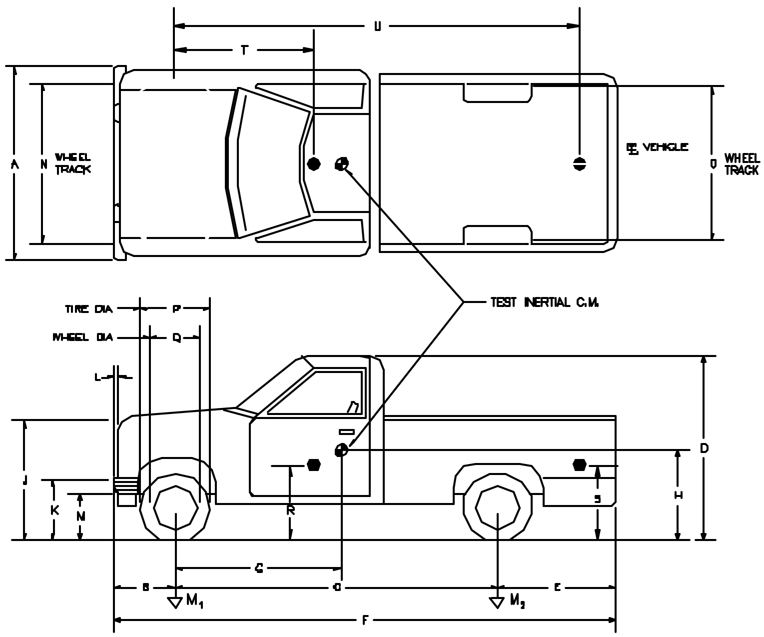
DATE: 02/20/02 TEST NO.: 400401-2 VIN NO.: 1GCGC24R1VZ205310

YEAR: 1997 MAKE: Chevrolet MODEL: 2500 Pickup Truck

TIRE INFLATION PRESSURE: ______ ODOMETER: 147817 TIRE SIZE: LT245 75R16

MASS DISTRIBUTION (kg) LF 571 RF 586 LR 444 RR 443

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



● Denotes accelerometer location.

NOTES: ______

ENGINE TYPE: 8 CYL

ENGINE CID: 5.7 L

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT: 8 LUGS

DUMMY DATA:

TYPE: ______

MASS: ______

SEAT POSITION: ______

GEOMETRY – (mm)

A 1870	E 1320	J 1090	N 1595	R 720
B 820	F 5490	K 655	O 1615	S 920
C 3350	G	L 95	P 720	T 1450
D 1780	H	M 435	Q 445	U 4000

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1234	1157	1157
M_2	925	887	887
M_T	2159	2044	2044

Figure 20. Vehicle properties for test 400401-2.

Table 5. Exterior crush measurements for test 400401-2.

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 ________	
$\geq$ 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		Field L**	C_1	C_2	C_3	C_4	C_5	C_6	±D
		Width** (CDC)	Max*** Crush								
1	Front bumper	600	340	-1730	-120	-180	-200	-240	-70	+30	0

[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).

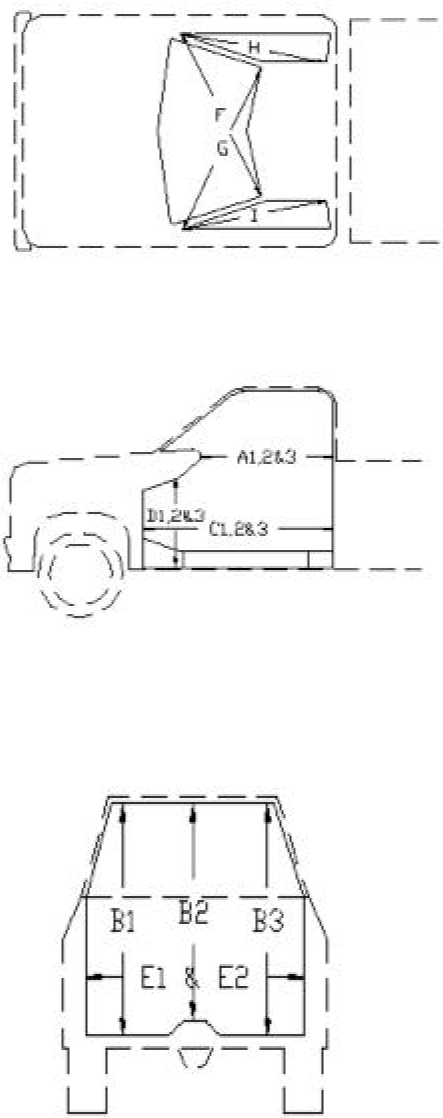
***Measure and document on the vehicle diagram the location of the maximum crush.

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

Table 6. Occupant compartment measurements for test 400401-2.

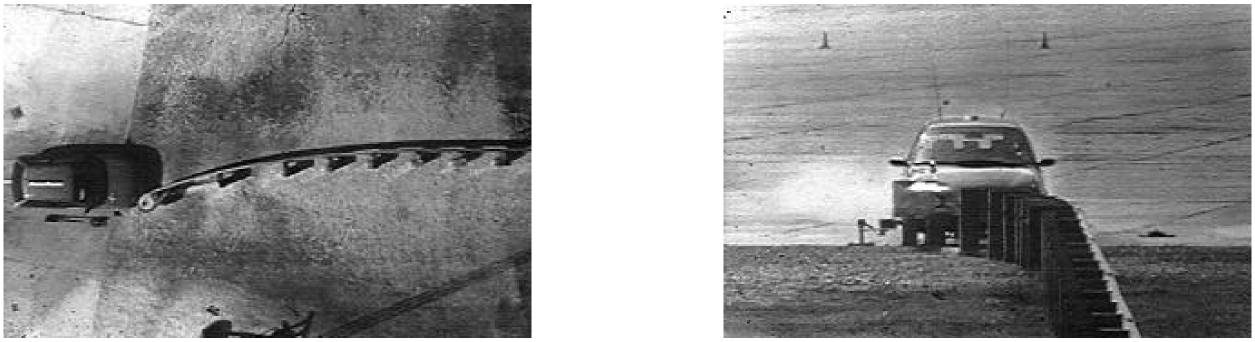
Truck

Occupant Compartment Deformation

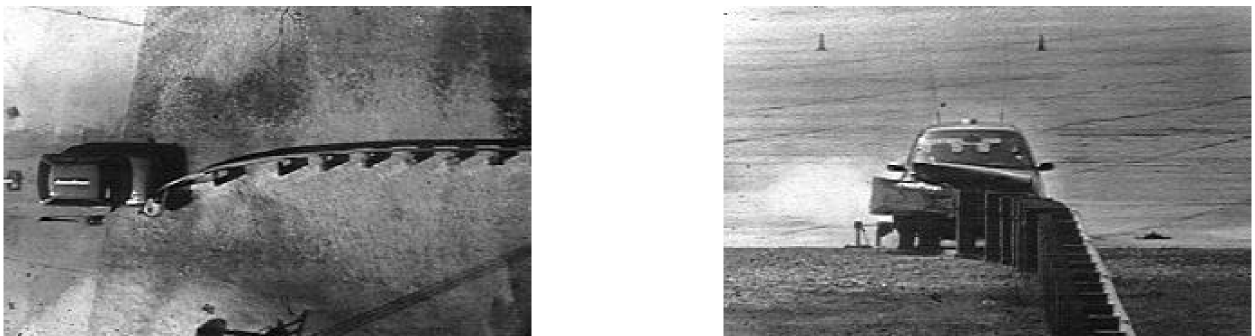


	BEFORE	AFTER
A1	872	872
A2	931	931
A3	910	910
B1	1075	1075
B2	1046	1046
B3	1075	1075
C1	1375	1375
C2	531	531
C3	1370	1370
D1	313	313
D2	157	157
D3	315	315
E1	1593	1593
E2	1583	1583
F	1460	1460
G	1460	1460
H	900	900
I	900	900
J	1525	1525

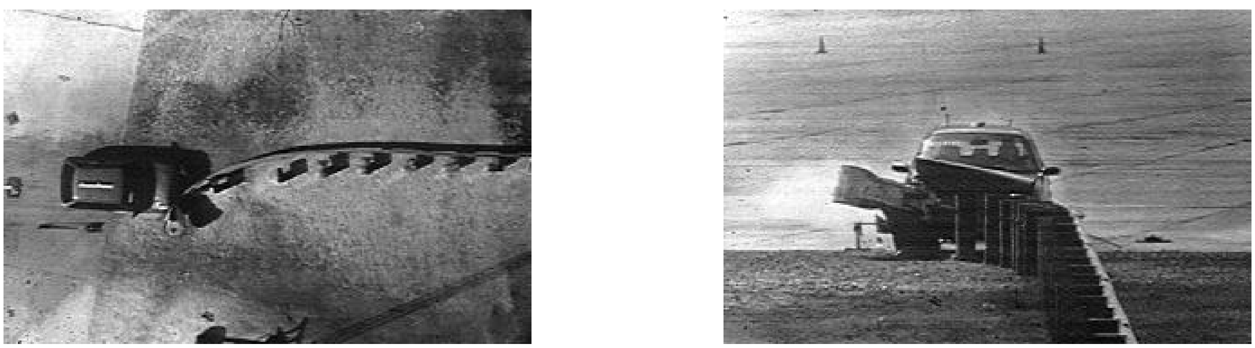
APPENDIX C. SEQUENTIAL PHOTOGRAPHS



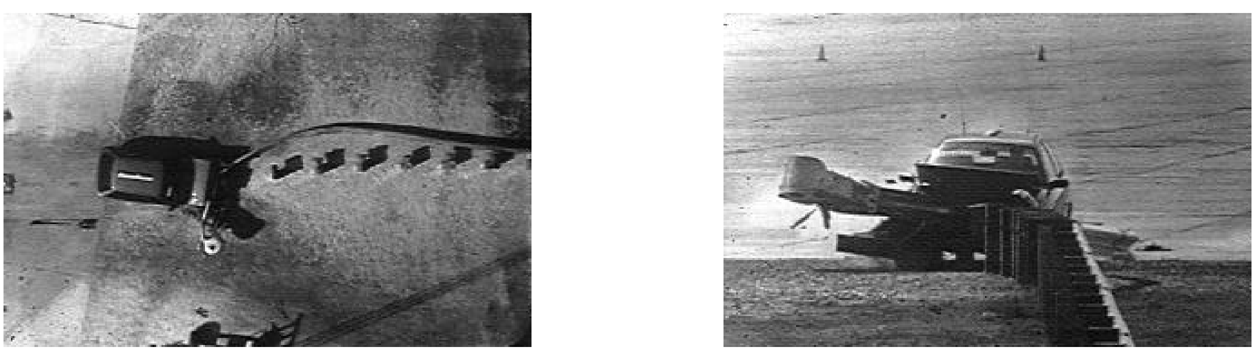
0.000 s



0.045 s

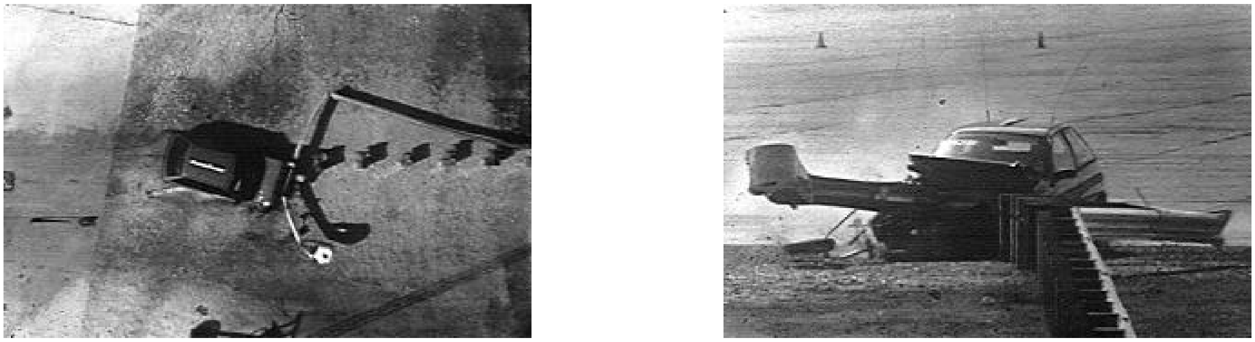


0.090 s

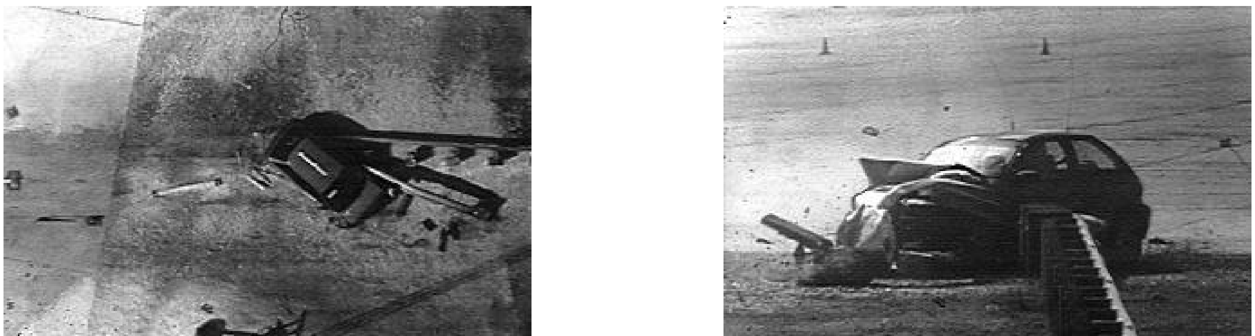


0.180 s

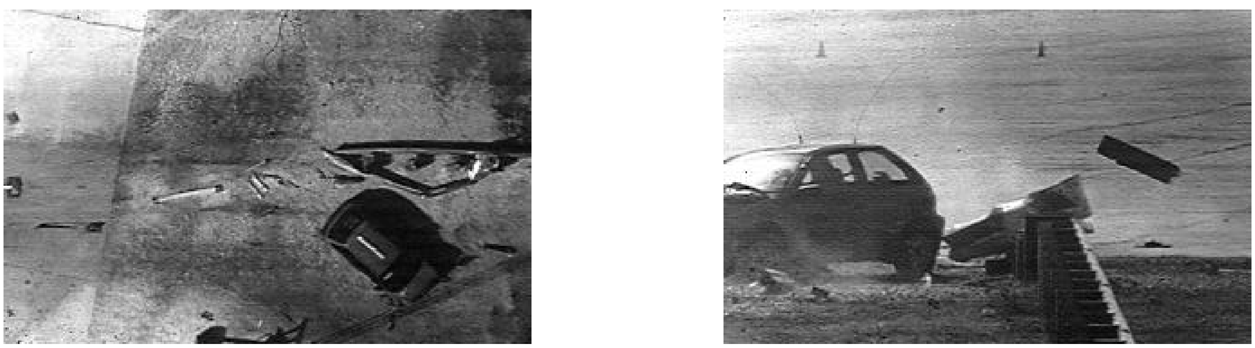
Figure 21. Sequential photographs for test 400401-1
(overhead and frontal views).



0.361 s



0.721 s

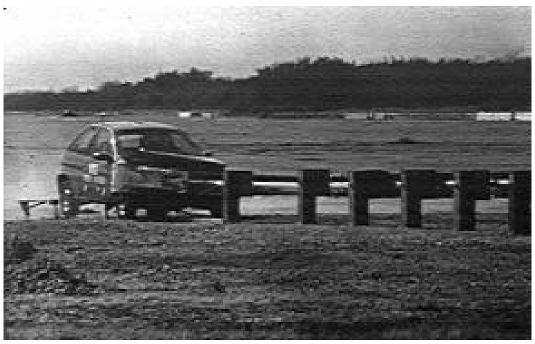


1.442 s

2.975 s

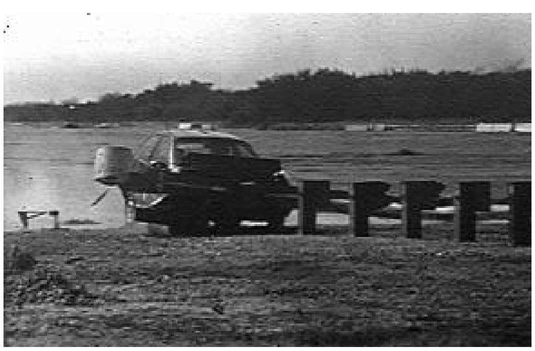
Figure 21. Sequential photographs for test 400401-1
(overhead and frontal views) (continued).

0.000 s



0.045 s

0.090 s



0.180 s

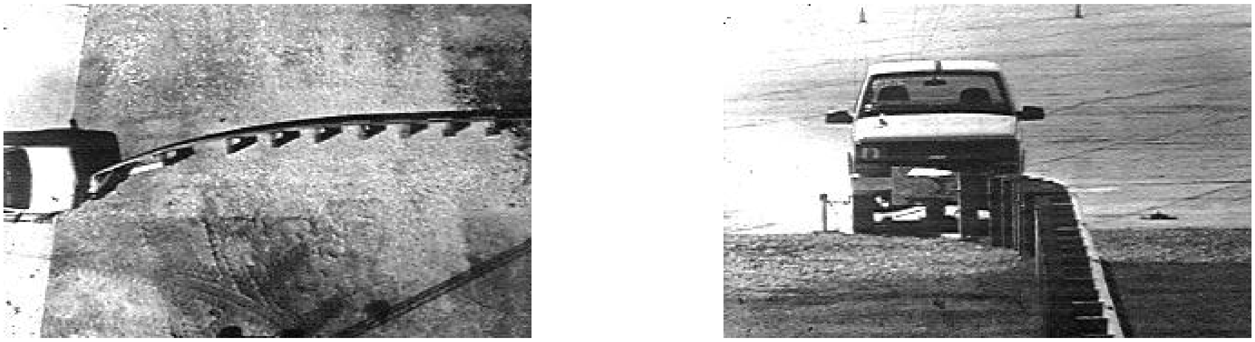
0.361 s

0.721 s

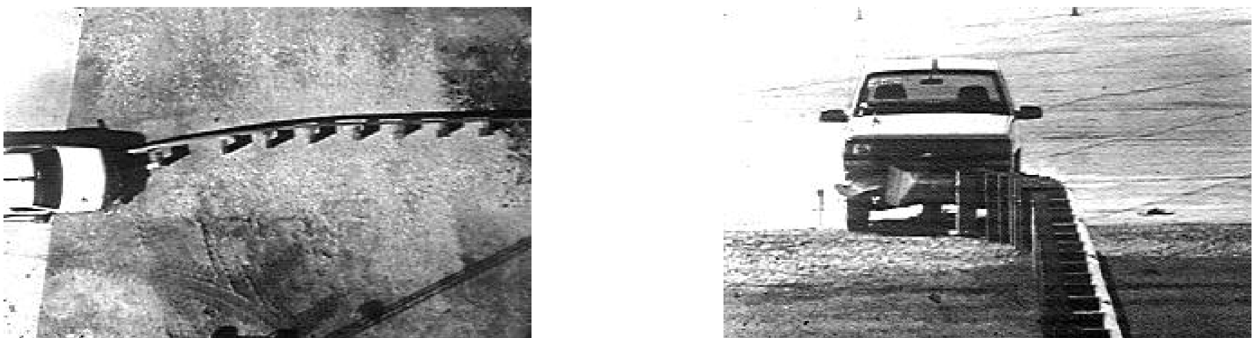
1.442 s

2.975 s

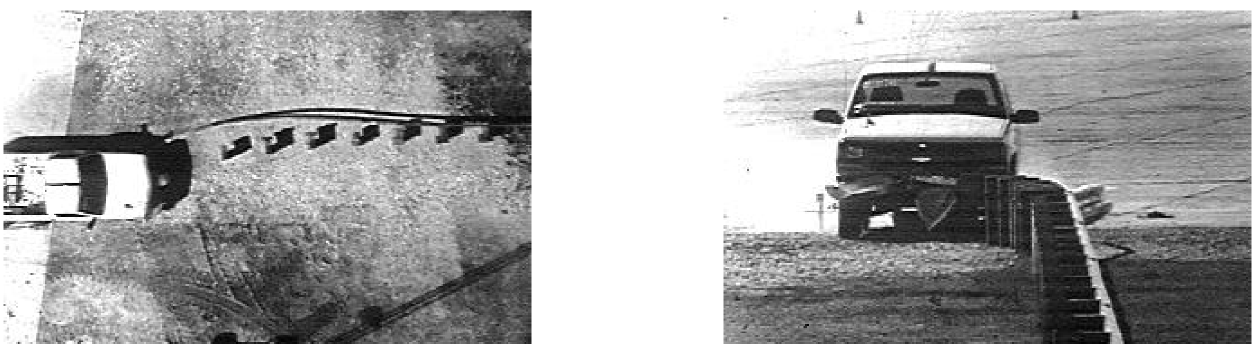
Figure 22. Sequential photographs for test 400401-1
(rear view).



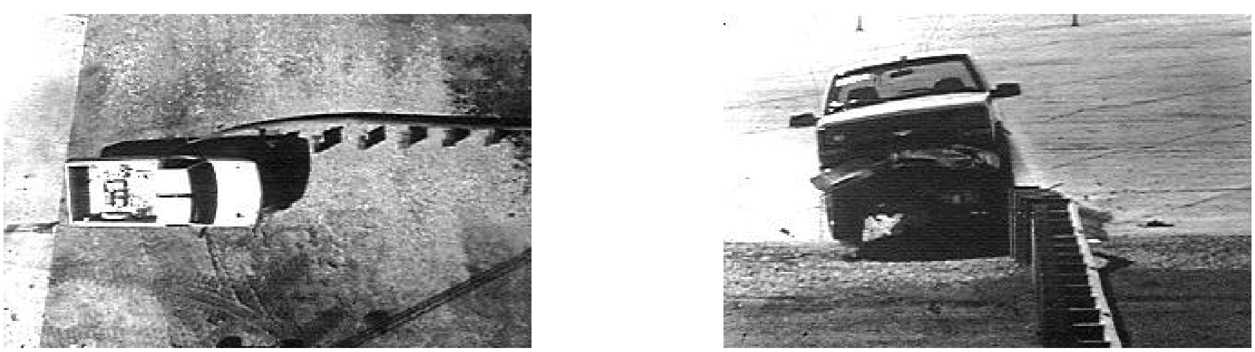
0.000 s



0.049 s

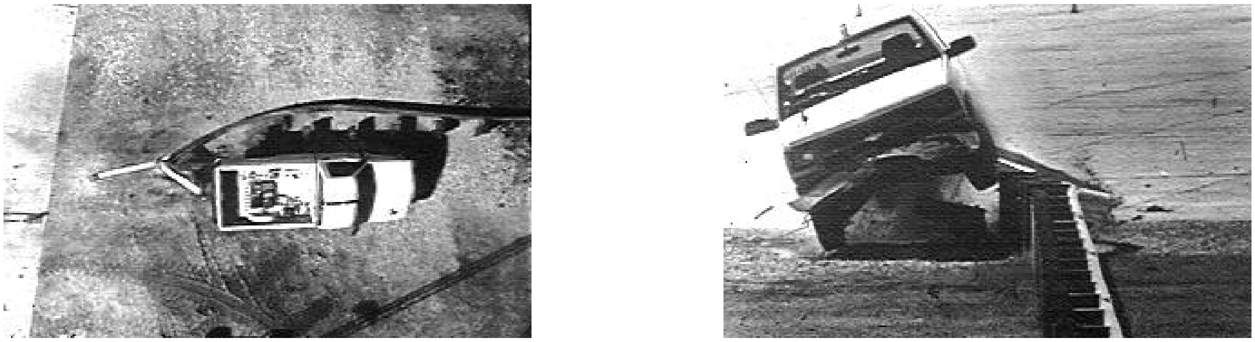


0.123 s



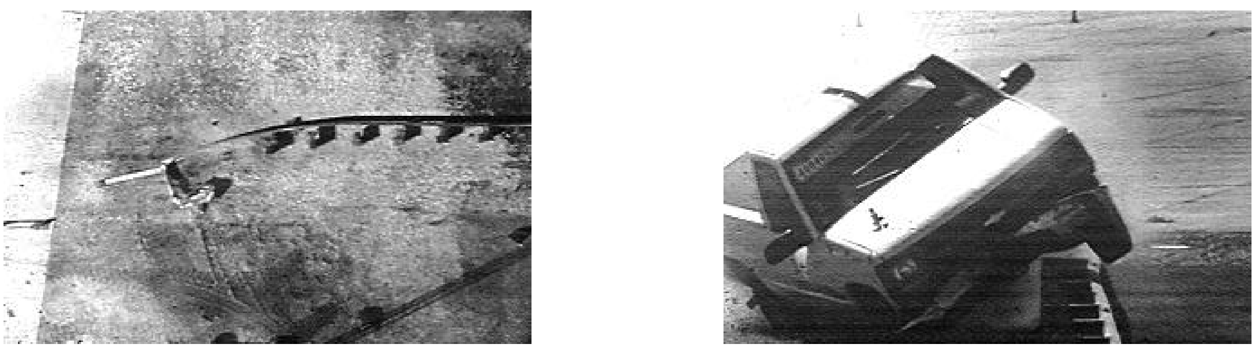
0.307 s

Figure 23. Sequential photographs for test 400401-2
(overhead and frontal views).

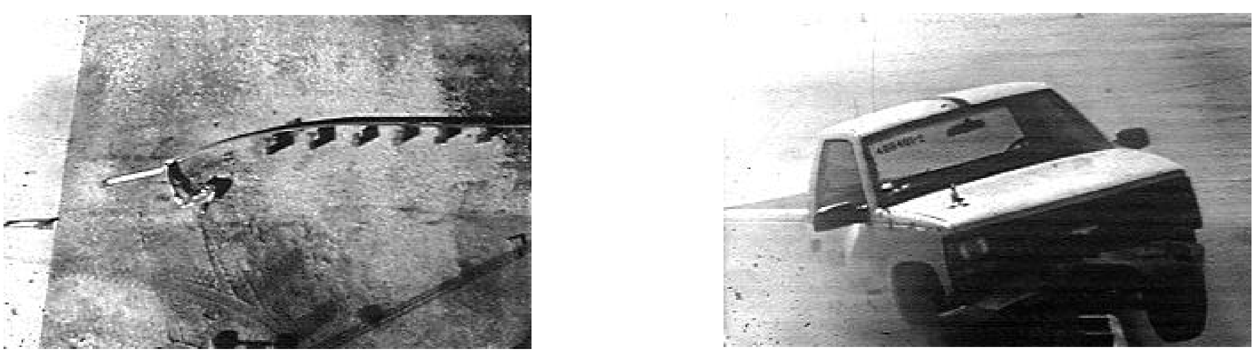


0.613 s

1.227 s

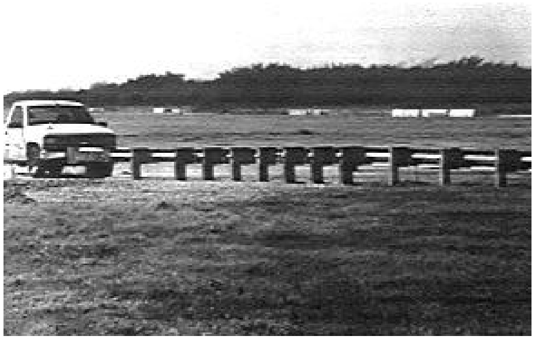


2.454 s



4.846 s

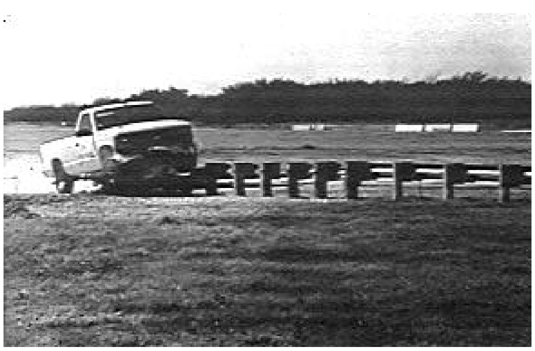
Figure 23. Sequential photographs for test 400401-2
(overhead and frontal views) (continued).



0.000 s

0.049 s

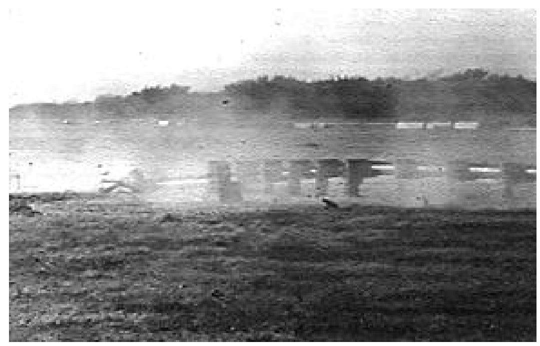
0.123 s



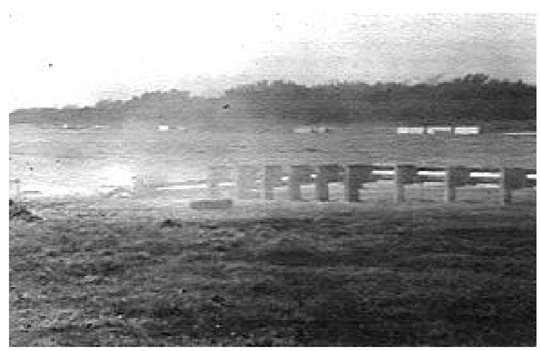
0.307 s

0.613 s

1.227 s



2.454 s



4.846 s

Figure 24. Sequential photographs for test 400401-2
(rear view).

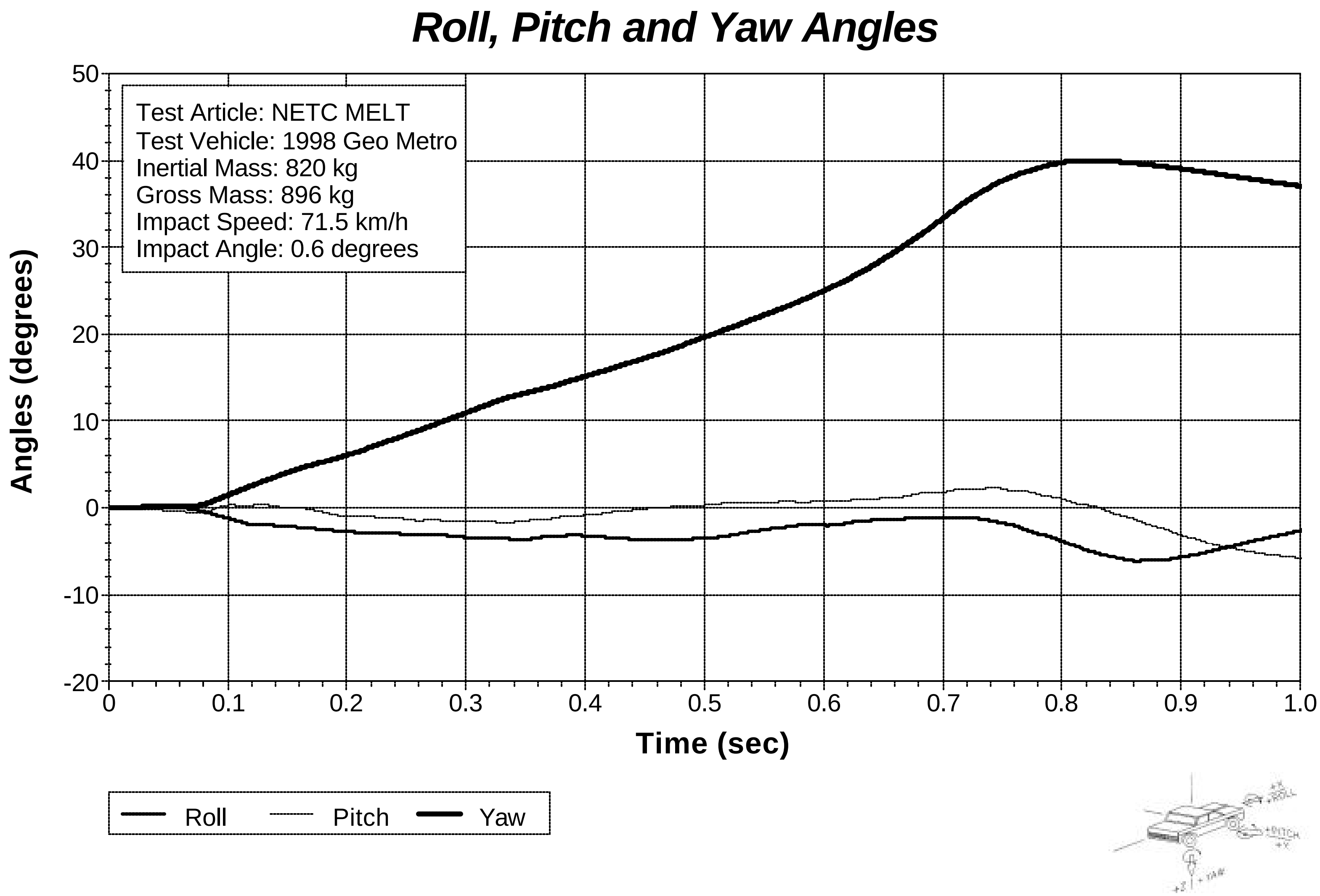


Figure 25. Vehicle angular displacements for test 400401-1.

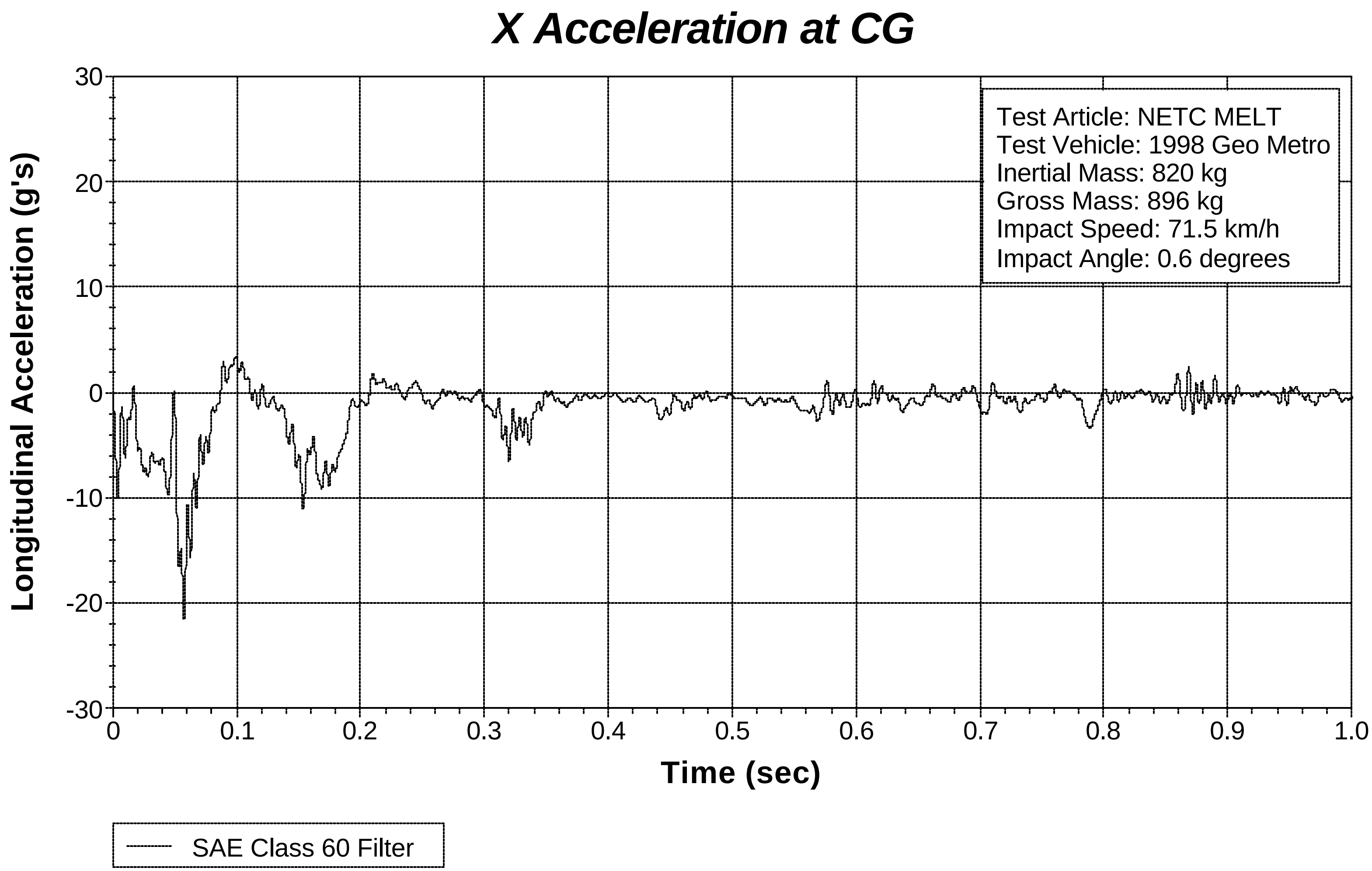


Figure 26. Vehicle longitudinal accelerometer trace for test 400401-1 (accelerometer located at center of gravity).

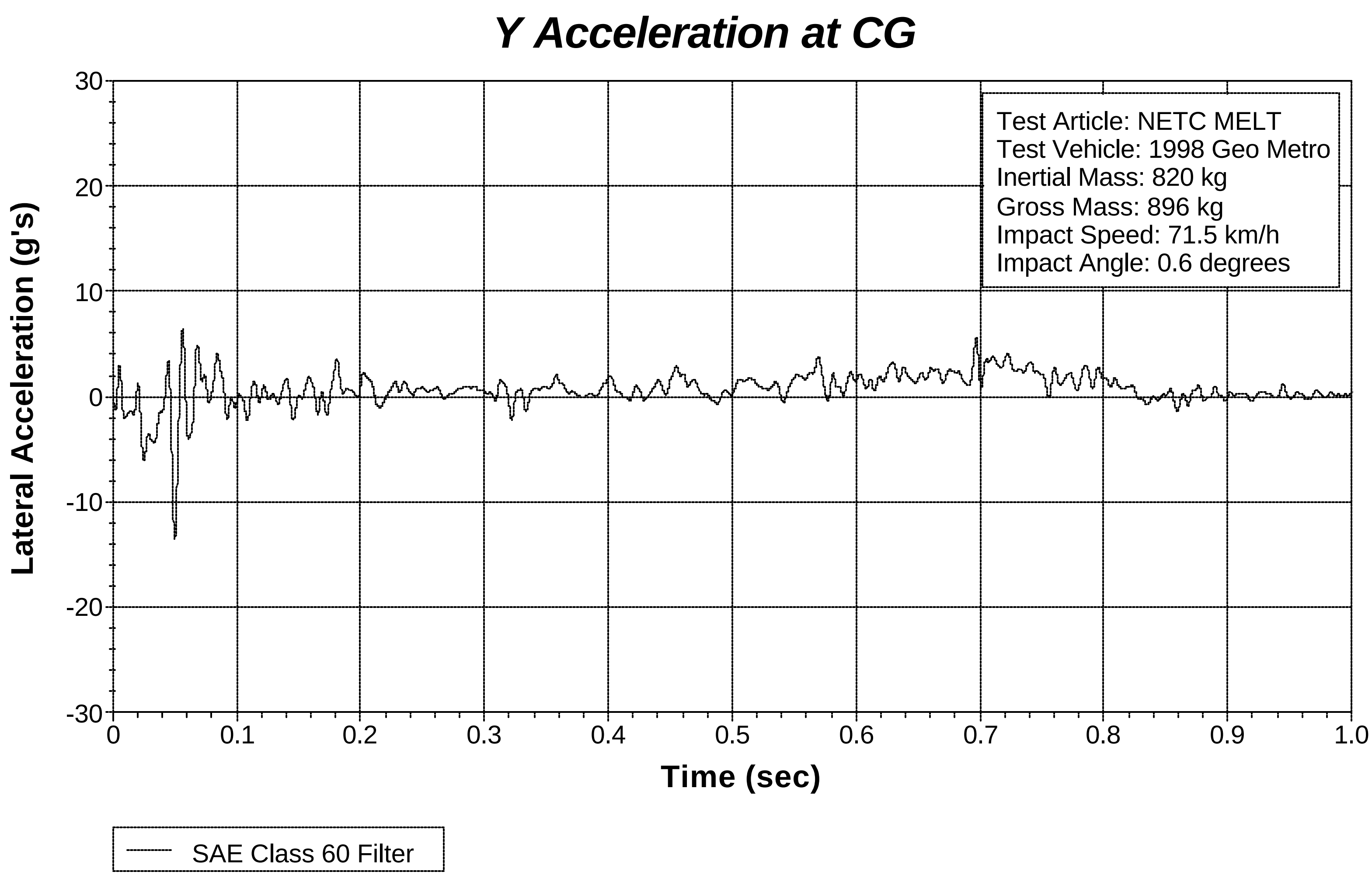


Figure 27. Vehicle lateral accelerometer trace for test 400401-1 (accelerometer located at center of gravity).

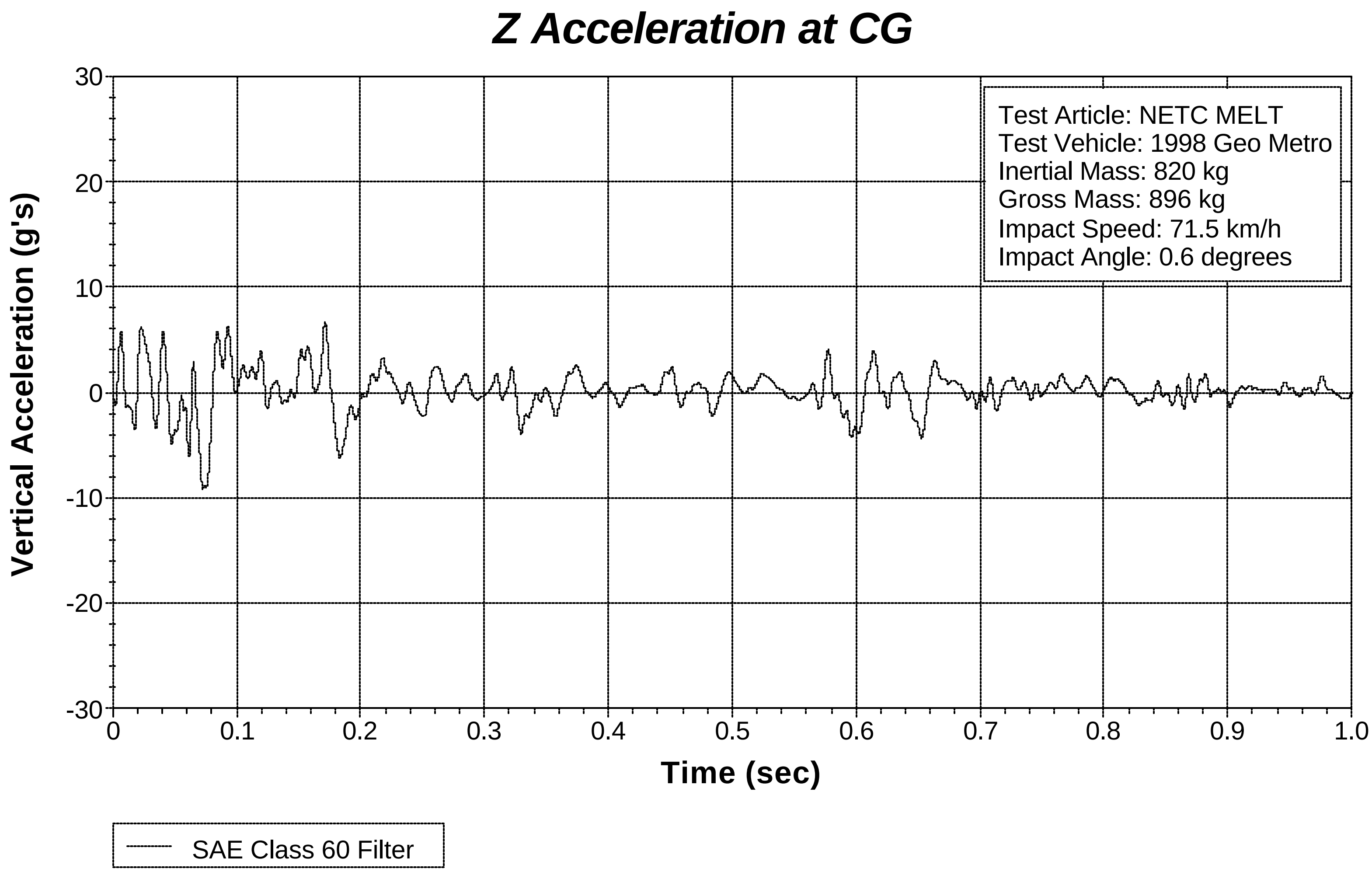


Figure 28. Vehicle vertical accelerometer trace for test 400401-1
(accelerometer located at center of gravity).

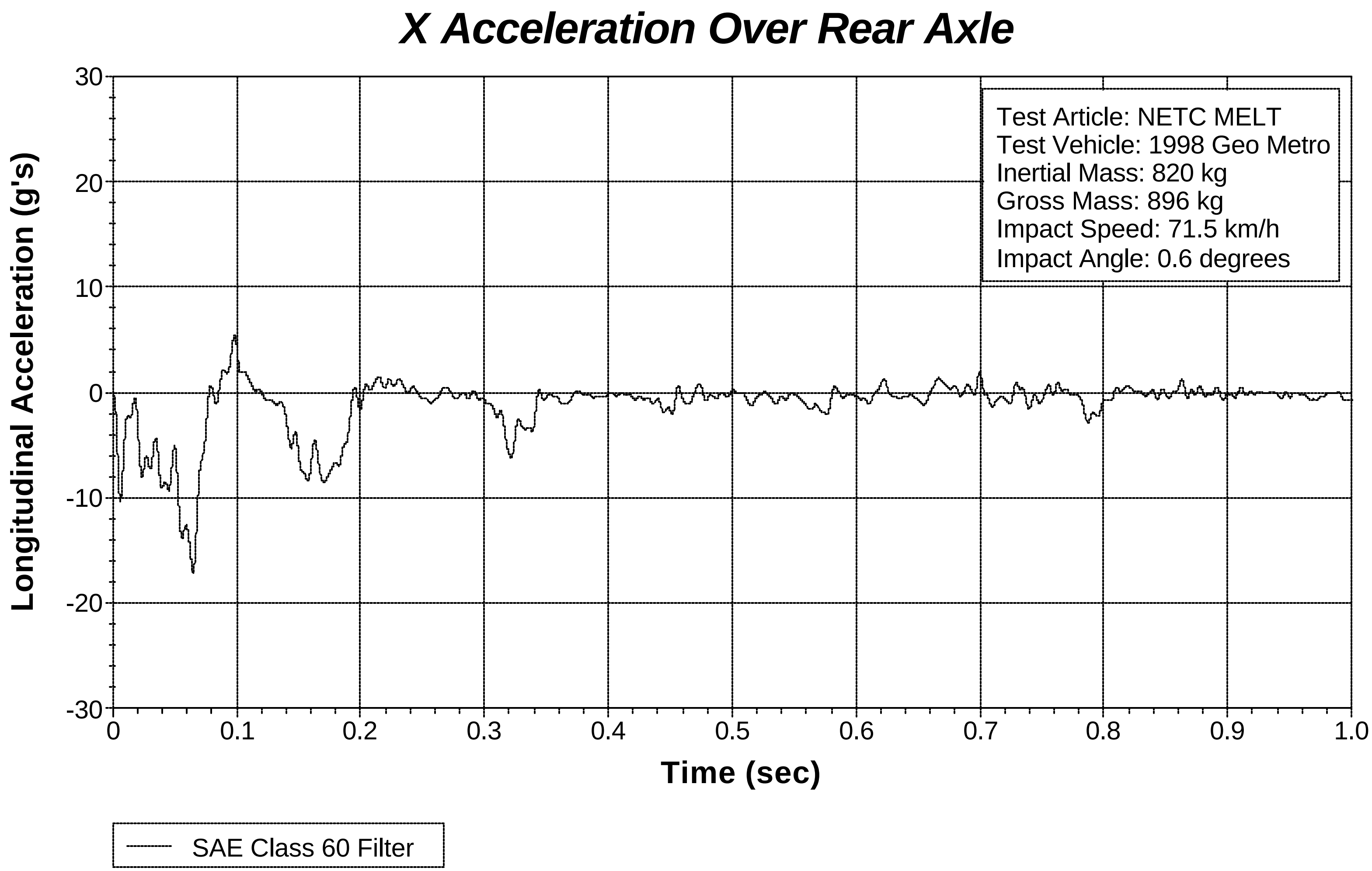


Figure 29. Vehicle longitudinal accelerometer trace for test 400401-1 (accelerometer located over rear axle).

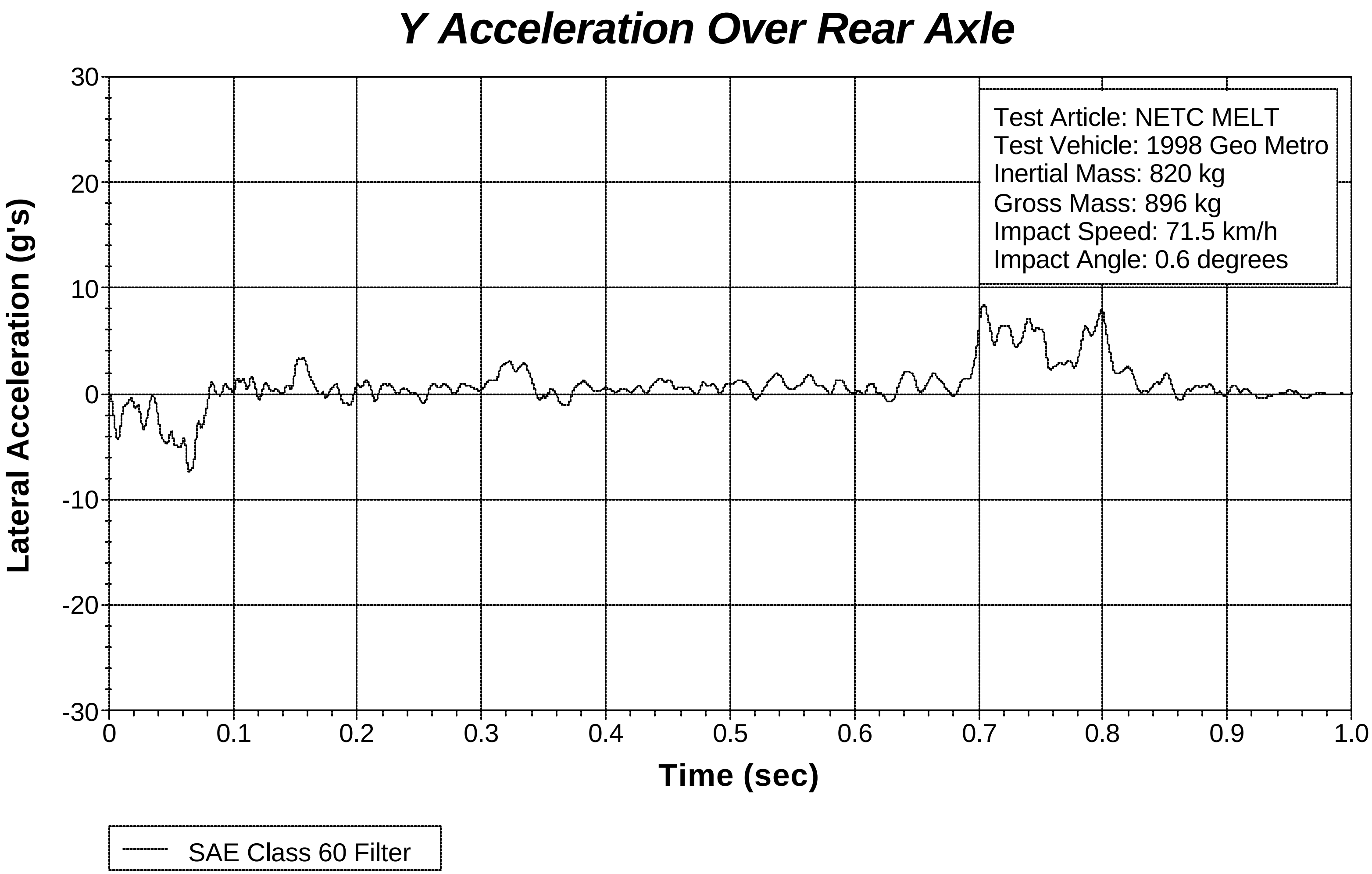


Figure 30. Vehicle lateral accelerometer trace for test 400401-1
(accelerometer located over rear axle).

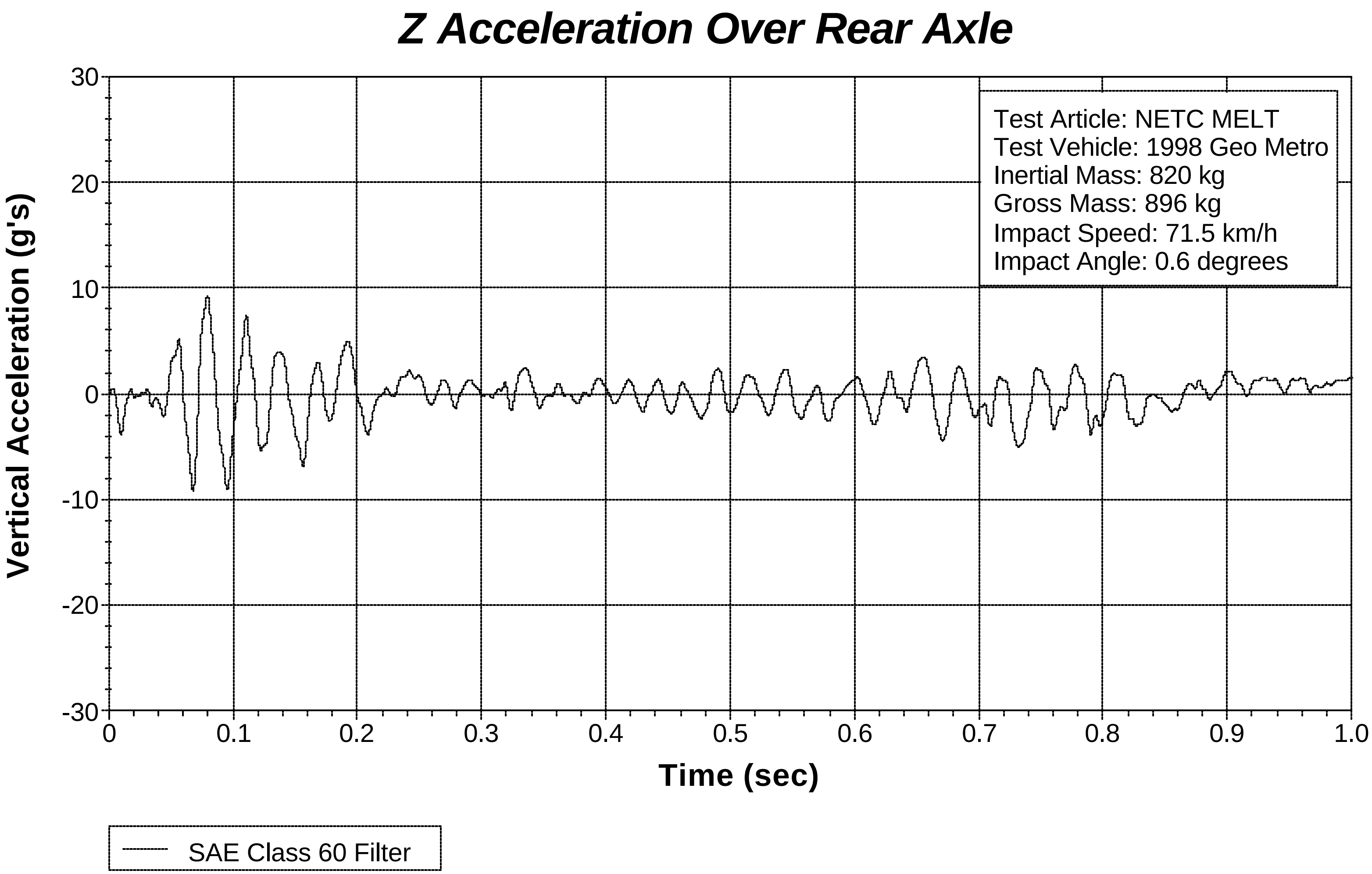


Figure 31. Vehicle vertical accelerometer trace for test 400401-1
(accelerometer located over rear axle).

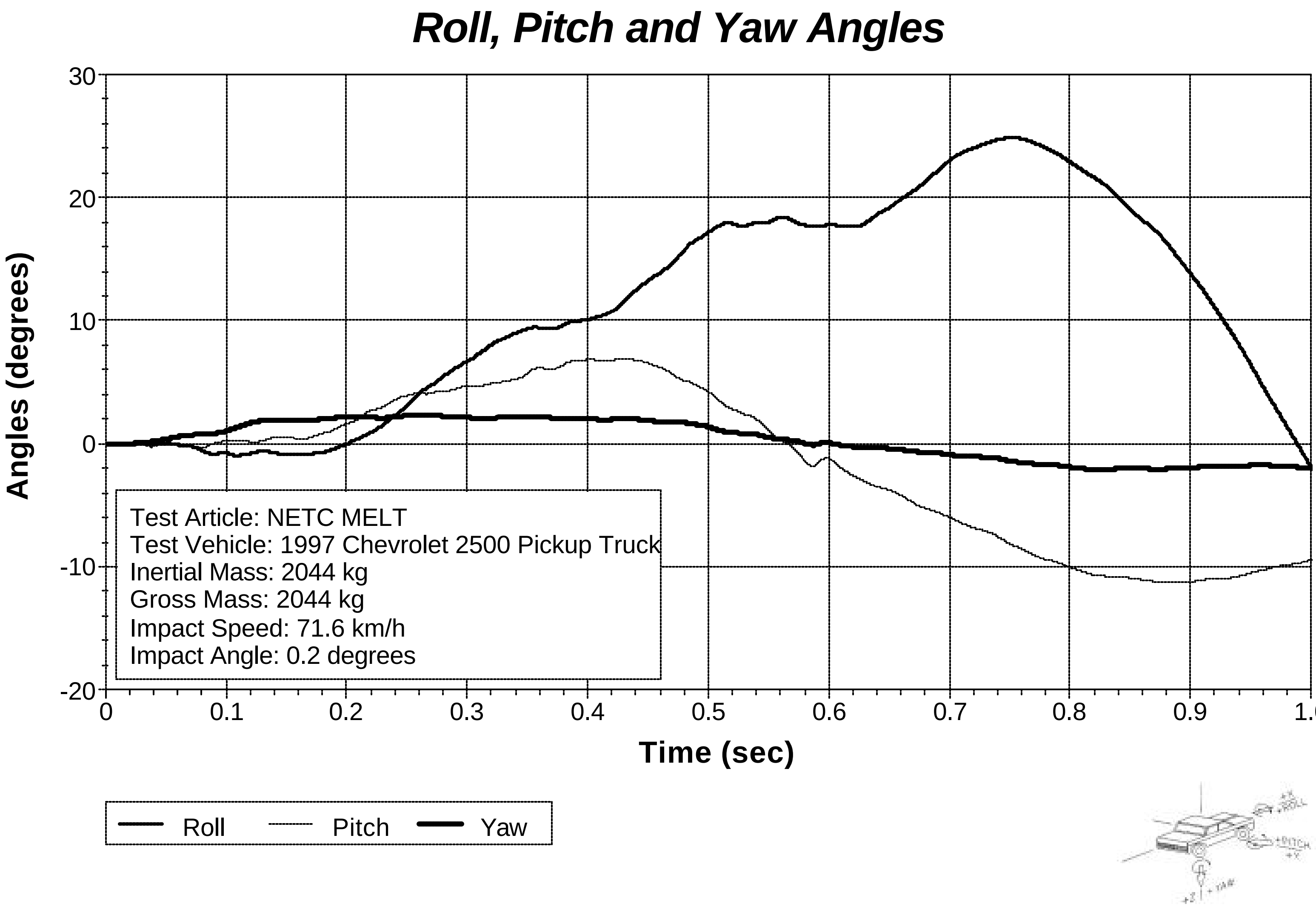


Figure 32. Vehicle angular displacements for test 400401-2.

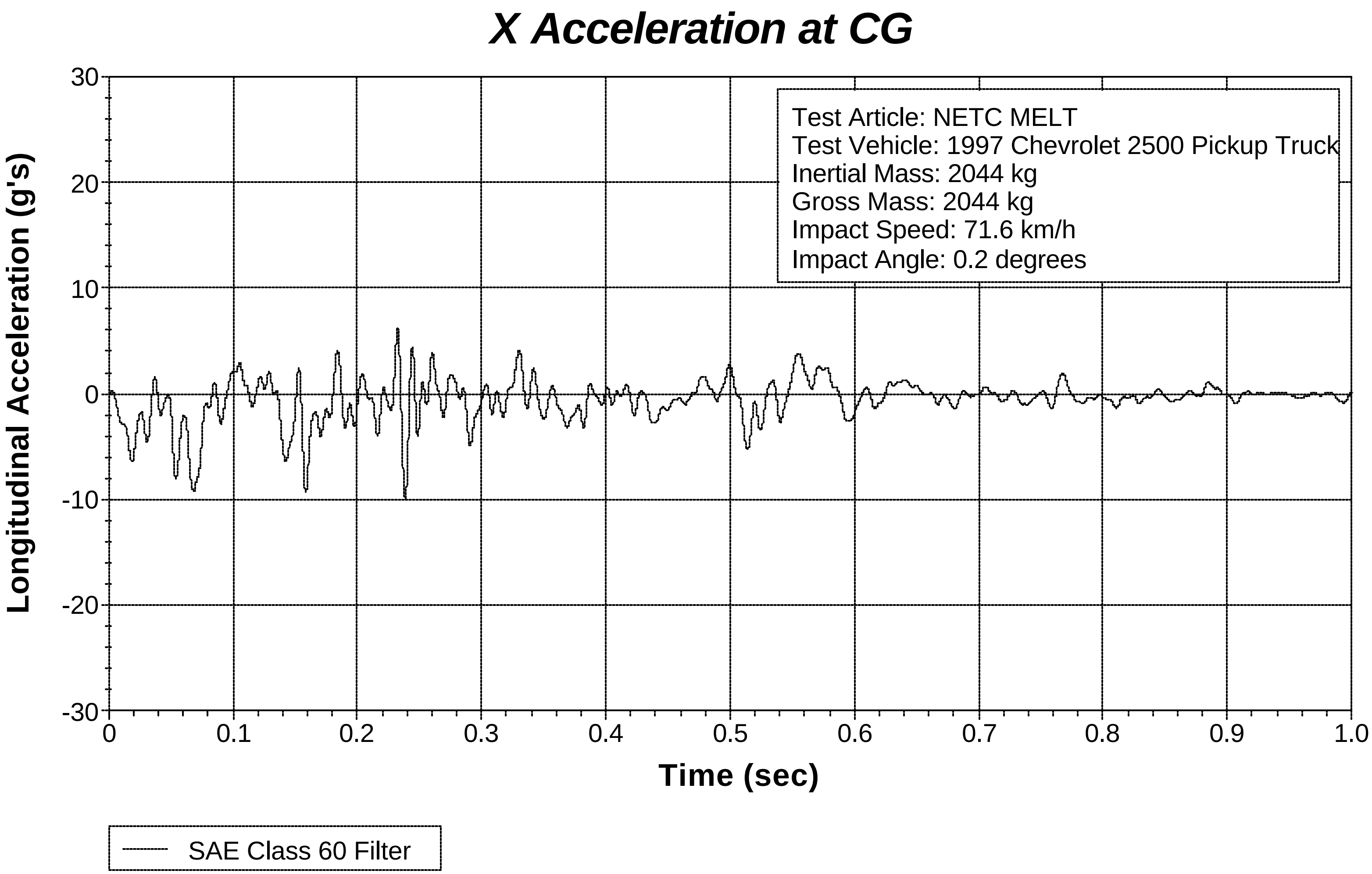


Figure 33. Vehicle longitudinal accelerometer trace for test 400401-2 (accelerometer located at center of gravity).

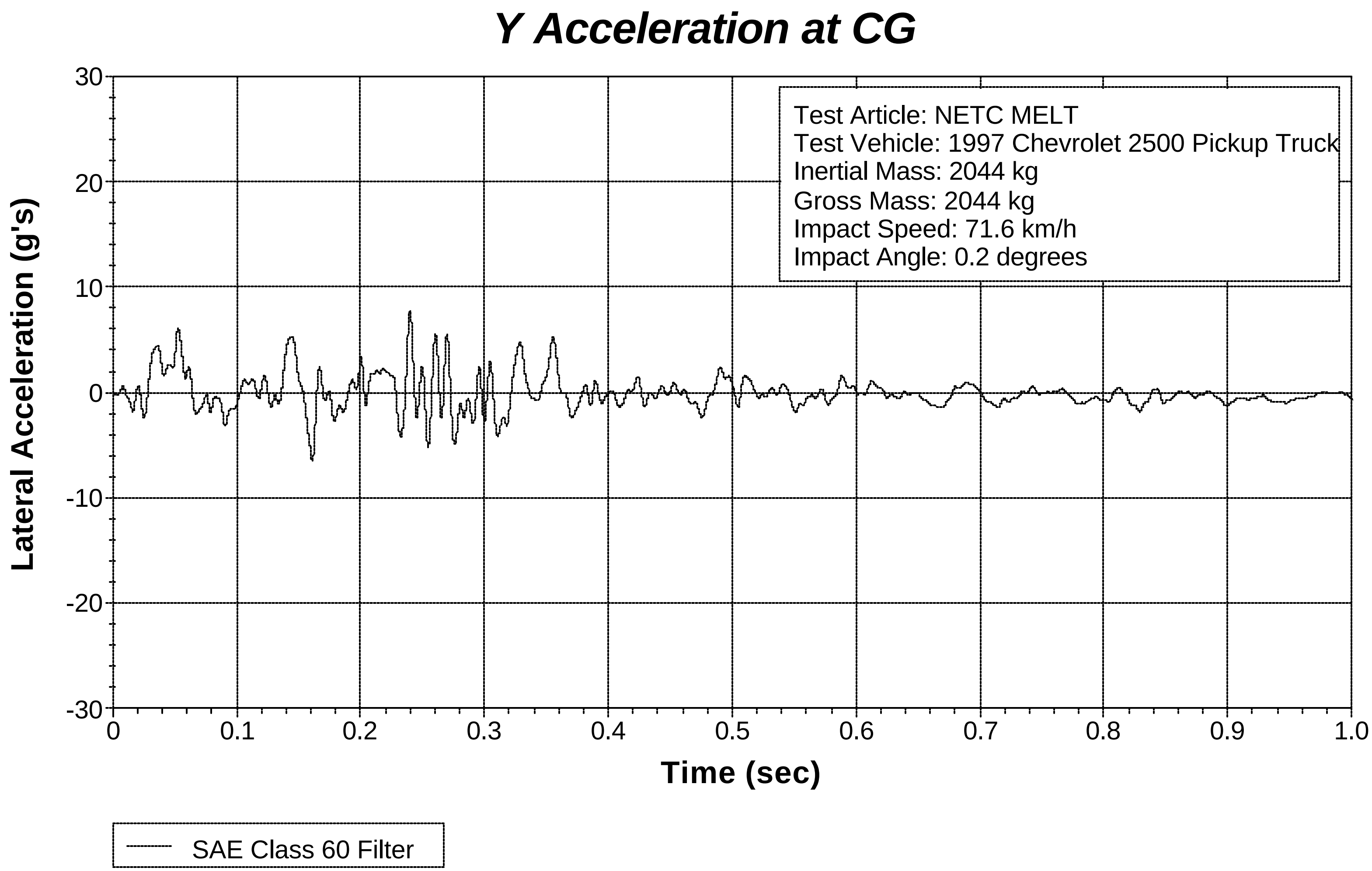


Figure 34. Vehicle lateral accelerometer trace for test 400401-2
(accelerometer located at center of gravity).

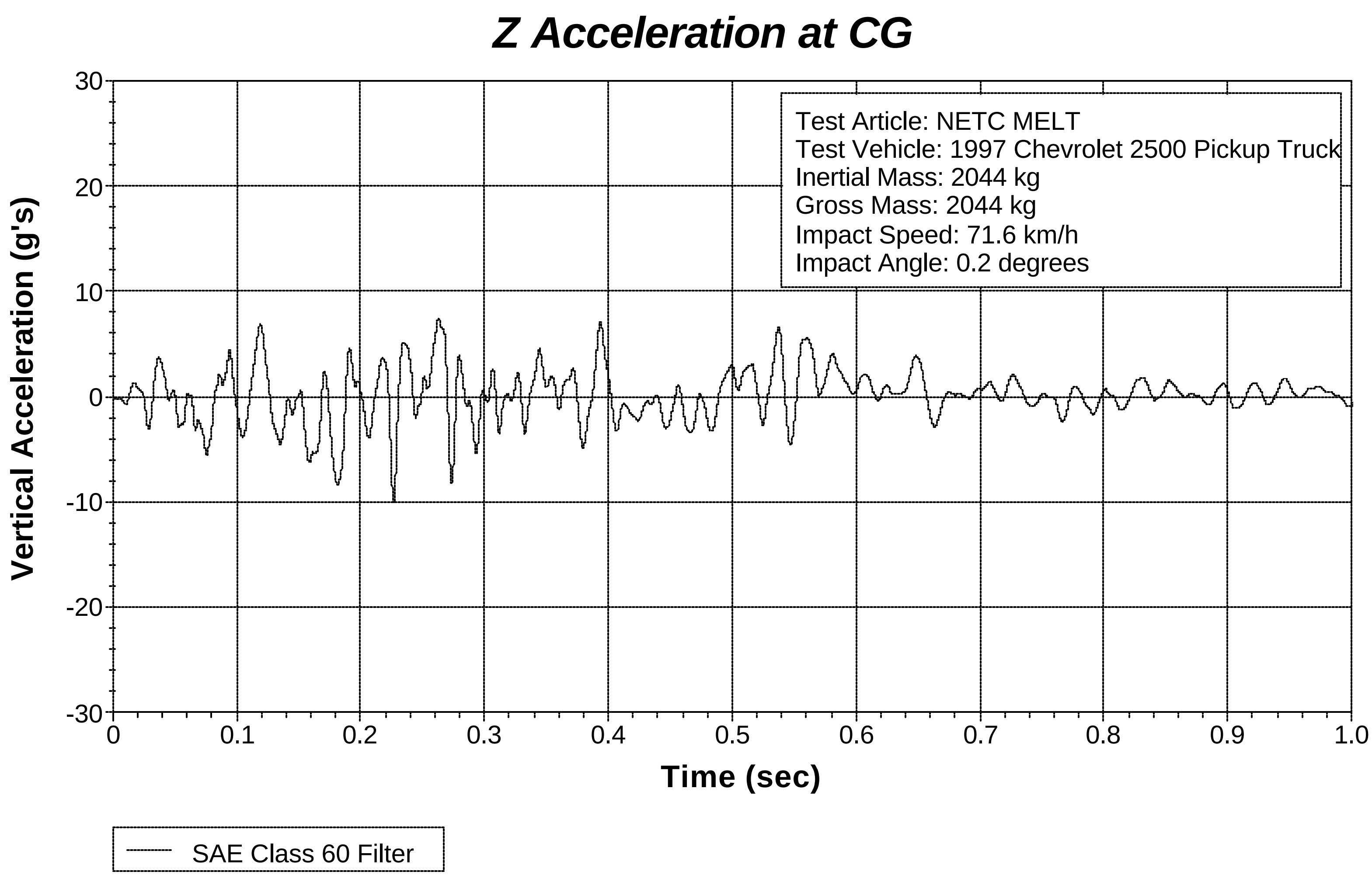


Figure 35. Vehicle vertical accelerometer trace for test 400401-2
(accelerometer located at center of gravity).

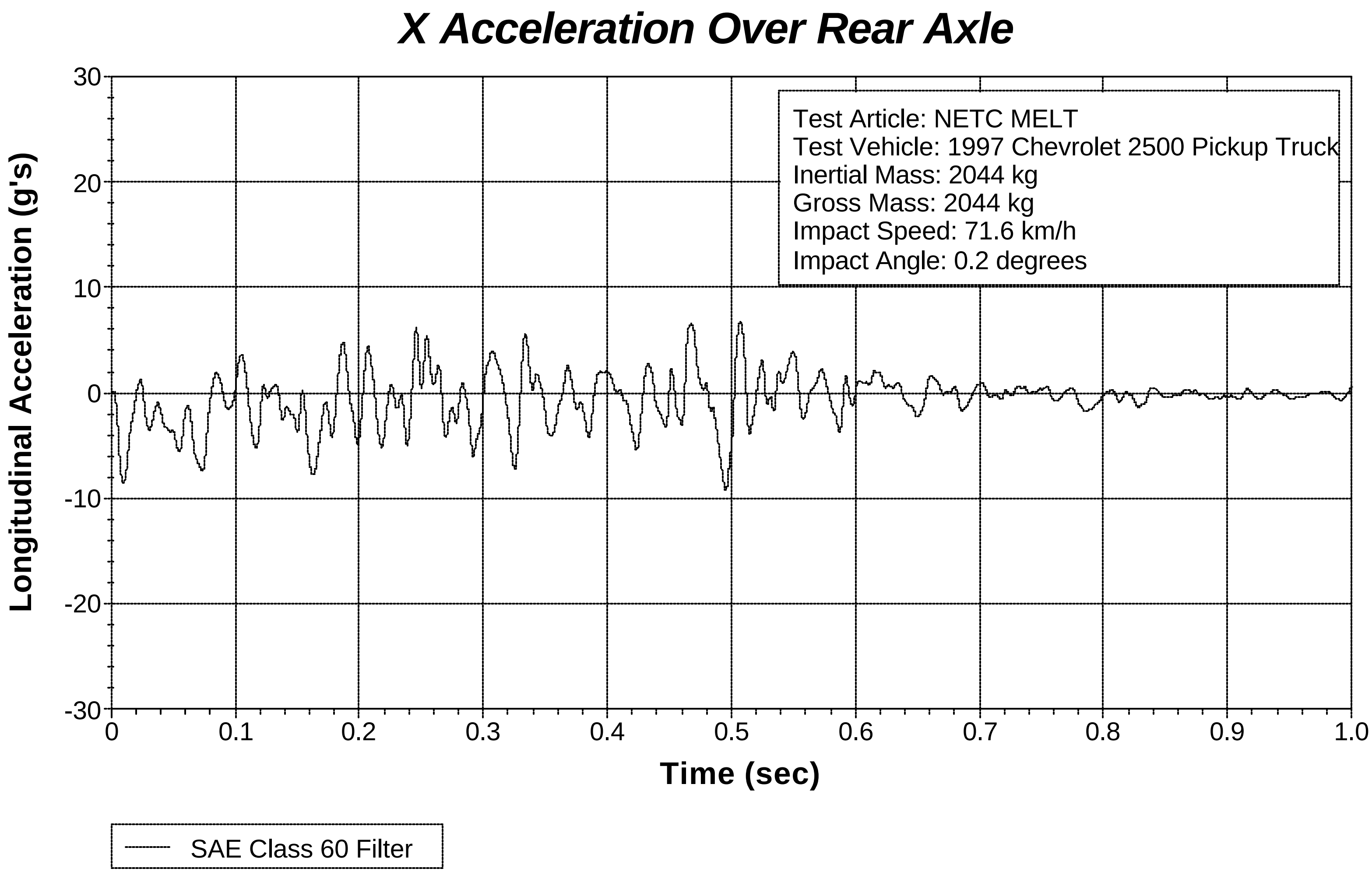


Figure 36. Vehicle longitudinal accelerometer trace for test 400401-2
(accelerometer located over rear axle).

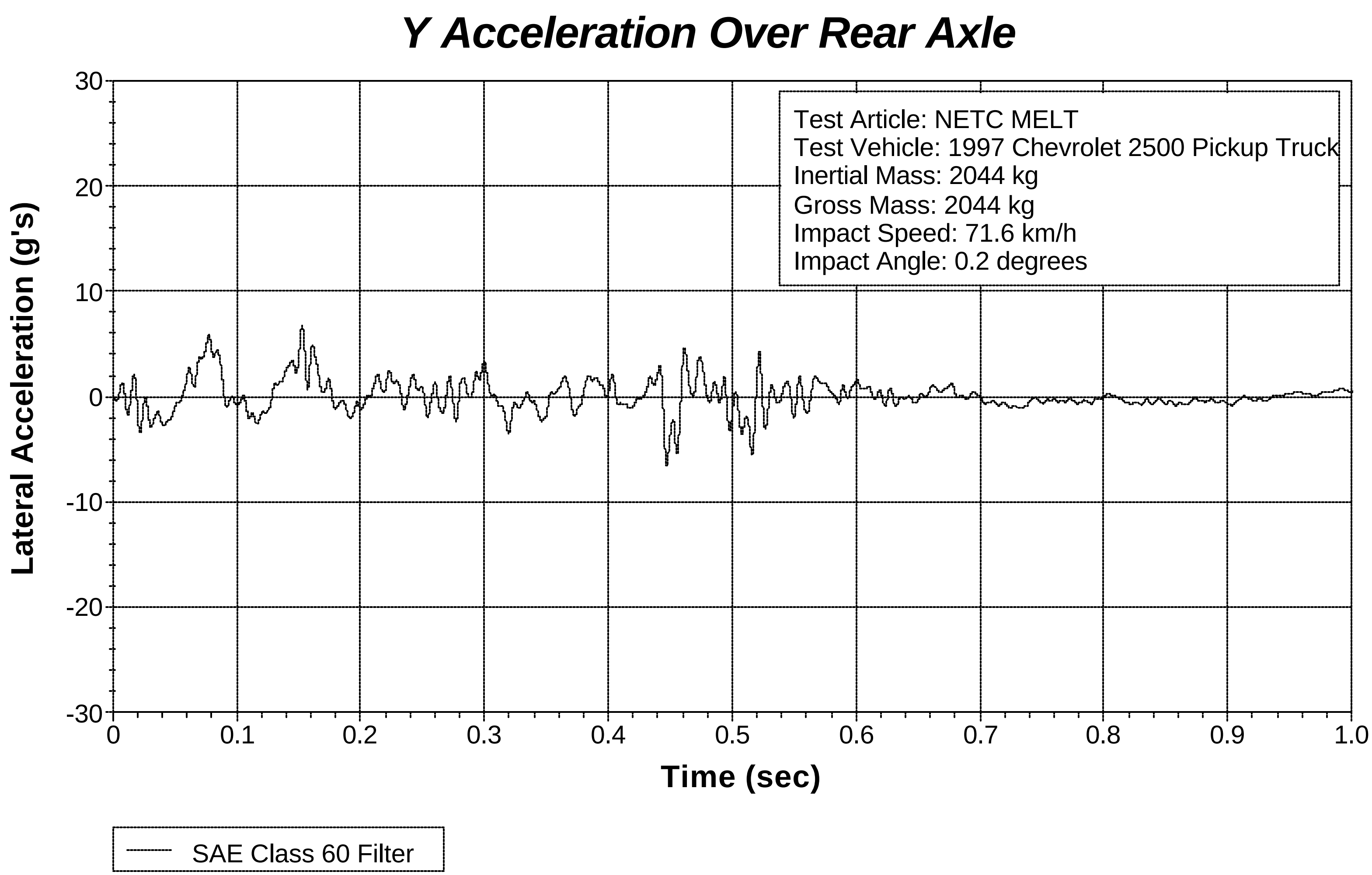


Figure 37. Vehicle lateral accelerometer trace for test 400401-2
(accelerometer located over rear axle).

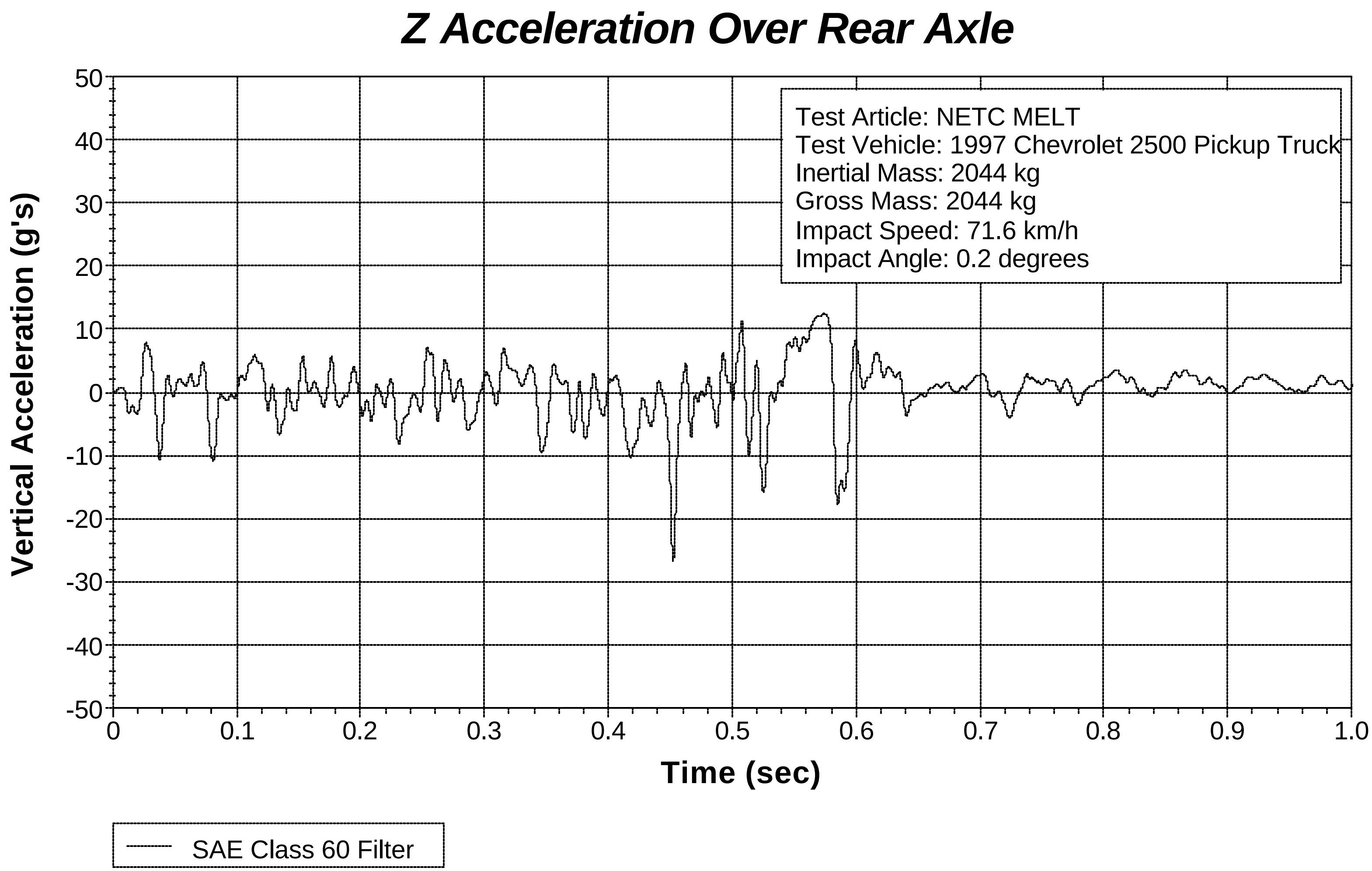


Figure 38. Vehicle vertical accelerometer trace for test 400401-2
(accelerometer located over rear axle).

REFERENCES

1. King K. Mak, Roger P. Bligh, and Wanda L. Menges, *Testing of State Roadside Systems*, Volume I: Technical Report, FHWA-RD-98-036, Federal Highway Administration, Washington, D.C., February 1998.

2. Dean C. Alberson, D. Lance Bullard, Jr., and Wanda L. Menges, *Testing and Evaluation of The Modified MELT*, TTI Report No. 405541-1, Texas Transportation Institute, The Texas A&M University, College Station, TX, January 1997.

3. King K. Mak, Roger P. Bligh, and Wanda L. Menges, *Testing and Evaluation of the MELT2 Terminal*, FHWA Contract DTFH61-95-C-00138, Texas Transportation Institute, The Texas A&M University System, College Station, TX, August 1996.

4. C. Eugene Buth, Wanda L. Menges, and Sandra K. Schoeneman, *Roadside Safety Hardware Tested in Accordance with NCHRP Report 350*, FHWA-RD-01-082, Federal Highway Administration, Washington, D.C., February 2001.

5. 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.

6. King K. Mak, Roger P. Bligh, and Wanda C. Menges, *W-Beam Slotted Rail End Terminal Design*, TTI Report No. 220530, Texas Transportation Institute, The Texas A&M University System, College Station, TX, May 1994.

7. King K. Mak, Hayes E. Ross, Jr., Roger P. Bligh, and Wanda L. Menges, *NCHRP Report 350 Compliance Testing of the W-Beam Slotted Rail Terminal*, TTI Report No. 220530 & 220536, Texas Transportation Institute, The Texas A&M University System, College Station, TX, October 1995.

8. King K. Mak, Hayes E. Ross, Jr., Roger P. Bligh, and Wanda L. Menges, *Optimization of the W-Beam Slotted Rail Terminal*, TTI Report No. 20546, Texas Transportation Institute, The Texas A&M University System, College Station, TX, May 1998.

9. Hayes E. Ross, Jr., Wanda L. Menges, and D. Lance Bullard, Jr., *NCHRP Report 350 Compliance Tests of the ET-2000*, TTI Report 220510 & 220537, Texas Transportation Institute, The Texas A&M University System, College Station, TX, August 1995.

10. Beam Eating Steel Terminal (BEST), http://www.unl.edu/matc/mwrswhat.htm, Midwest Roadside Safety Facility, University of Nebraska, Lincoln, NB.

11. Sequential Kinking Terminal (SKT-350), http://www.roadsystems.com, Road Systems Inc., 3616 Old Howard County Airport, Big Spring, TX.

12. Flared Energy Absorbing Terminal (FLEAT-350), http://www.roadsystems.com, Road Systems Inc., 3616 Old Howard County Airport, Big Spring, TX.