File In:

Terminals

END TERMINAL FOR BOX-BEAM MEDIAN BARRIER

FINAL REPORT

By

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Research Engineer

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and

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Assistant Research Specialist

Project No. RF 72020

Sponsored by

Wyoming Department of Transportation
Cheyenne, Wyoming

June 1995

Texas Transportation Institute
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

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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	Mg
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
	ILLUMINATION			
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.45	newtons	N
psi	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	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
	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	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	Celcius 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	psi

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

(Revised August 1992)

DISCLAIMER

The contents of this report reflect the views of the authors who are solely responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Wyoming Department of Transportation (Wyoming DOT) or the Federal Highway Administration (FHWA). This report does not constitute a standard, specification or regulation.

KEY WORDS

Box-Beam Median Barrier, End Treatment, End Terminal, Highway Safety

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I. INTRODUCTION

A crashworthy end terminal for box-beam guardrails was previously designed, developed, and successfully crash tested under this study.[1,2] The design and crash test results were reviewed by the Federal Highway Administration (FHWA) and approved for field installation.[3] A design adapting the guardrail end terminal for use with box-beam median barriers was also developed[2], but upon review by FHWA, some concerns were expressed regarding the median barrier end terminal design and additional crash tests were requested prior to approval for field implementation. The concerns expressed by FHWA and the required additional crash tests are summarized as follows:

1. A vehicle may snag on the cable anchor before breaking off the end post in a reverse direction impact. A reverse direction test involving an 1,800-lb (817-kg) passenger car impacting the end terminal in the reverse direction mid-point between the nose and the beginning of length-of-need at a nominal speed of 60 mi/h (96.6 km/h) and at an angle of 20 degrees was suggested.
2. The median barrier terminal design offers significantly less lateral resistance throughout its length. A length-of-need strength test involving a 4,500-lb (2,041-kg) passenger car impacting the end terminal at the beginning of length-of-need at a nominal speed of 60 mi/h (96.6 km/h) and at an angle of 25 degrees was suggested.

The objective of this portion of the study was, therefore, to crash test and evaluate the box-beam median barrier end terminal design in accordance with concerns expressed by FHWA in order to qualify the end terminal design for field implementation.

This report summarizes the results of the effort involved in crash testing and evaluating the box-beam median barrier end terminal design. Chapter II of the report outlines the study approach. Detailed descriptions of the final end terminal design is presented in Chapter III of the report. Results of the crash tests are documented in Chapter IV of the report. Chapter V presents the study findings, conclusions and recommendations. Standard drawings prepared by the Wyoming Department of Transportation (Wyoming DOT) on the box-beam guardrail, box-beam median barrier, box-beam guardrail end terminal (WY-BET), and box-beam median barrier end terminal (WY-BET[MB]) are shown in Appendix A. Descriptions and discussions on revisions to the design details incorporated by the Wyoming DOT into its standard drawings are presented in Appendix B.

II. STUDY APPROACH

2.1 Crash Test Matrix

As mentioned previously, two additional crash tests were required by FHWA in order to qualify the box-beam median barrier end terminal design for field implementation:

1. An 1,800-lb (817-kg) passenger car impacting the end terminal in the reverse direction mid-point between the nose and the beginning of length-of-need at a nominal speed and angle of 60 mi/h (96.6 km/h) and 20 degrees.
2. A 4,500-lb (2,041-kg) passenger car impacting the end terminal at the beginning of length-of-need at a nominal speed and angle of 60 mi/h (96.6 km/h) and 25 degrees.

A total of five crash tests were conducted. The first reverse direction test and the first two length-of-need strength tests resulted in unsatisfactory impact performance of the end terminal. Modifications were then made to the end terminal design and the tests were repeated with successful results. The crash test results are presented in Chapter IV of the report.

2.2 Crash Testing Procedures

All crash test and data analysis procedures were conducted in accordance with guidelines contained in NCHRP Report 230.[4] Brief descriptions of the crash test and data analysis procedures are presented as follows.

2.3.1 Electronic Instrumentation and Data Processing

Each test vehicle was instrumented with three solid-state angular rate transducers to measure roll, pitch and yaw rates; a triaxial accelerometer at the vehicle center-of-gravity 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. The accelerometers were strain gauge type with a linear millivolt output proportional to acceleration.

The electronic signals from the accelerometers and transducers were transmitted to a base station by means of constant bandwidth FM/FM telemetry link for recording on magnetic tape and

for display on a real-time strip chart. Provision was made for the transmission of calibration signals before and after the test, and an accurate time reference signal was simultaneously recorded with the data. Pressure sensitive contact switches on the bumper were actuated just 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 produced an "event" mark on the data record to establish the exact instant of contact with the barrier.

The multiplex of data channels, transmitted on one radio frequency, was received at a data acquisition station, and demultiplexed into separate tracks of Intermediate Range Instrumentation Group (I.R.I.G.) tape recorders. After the test, the data was played back from the tape machines, filtered with a SAE J211 Class 180 filter, and were digitized using a microcomputer, for analysis and evaluation of impact performance. The digitized data were then processed using two computer programs: DIGITIZE and PLOTANGLE. Brief descriptions on the functions of these programs are given below.

The DIGITIZE program uses digitized data from vehicle-mounted linear accelerometers to compute occupant/compartment impact velocities, time of occupant/compartment impact after vehicle impact, and the highest 10-msec average ridedown acceleration. The DIGITIZE program also calculates a vehicle impact velocity and the change in vehicle velocity at the end of a given impulse period. In addition, maximum average accelerations over 50-msec intervals in each of the three directions are computed. Acceleration versus time curves for the longitudinal, lateral, and vertical directions are then plotted from the digitized data of the vehicle-mounted linear accelerometers using a commercially available software package.

The PLOTANGLE program uses the digitized data from the yaw, pitch, and roll rate charts to compute angular displacement in degrees at 0.00067-second intervals and then instructs a plotter to draw a reproducible plot of yaw, pitch, and roll versus time. It should be noted that these angular displacements are sequence dependent with the sequence being yaw-pitch-roll for the data presented herein. These displacements are in reference to the vehicle-fixed coordinate system with the initial position and orientation of the vehicle-fixed coordinate system being that which existed at the point of initial impact.

2.3.2 Photographic Instrumentation and Data Processing

Photographic coverage of each 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 to have a field of view parallel to and aligned with the barrier at the downstream end; and a third placed behind the barrier at an angle. A flash bulb activated by pressure sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the barrier 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 and a 3/4-in videotape camcorders and still cameras were used for documentary purposes and to record conditions of the test installation and vehicle before and after the test.

2.3.3 Test Vehicle Propulsion and Guidance

The test vehicles were towed into the barrier using a steel cable guidance and reverse tow system. A steel cable for guiding the test vehicles was stretched along the impact path, anchored at each end, and threaded through an attachment to the front wheel of the test vehicle. Another steel cable was connected to the test vehicles, passed around a pulley near the impact point, through a pulley on the tow vehicle, and then anchored to the ground such that the tow vehicle moved away from the test site. A 2 to 1 speed ratio between the test and tow vehicle existed with this system. Just prior to impact with the barrier, 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 the vehicle to a safe and controlled stop.

III. BOX-BEAM MEDIAN BARRIER END TERMINAL DESIGN

3.1 Telescoping Tube Terminal Concept

The box-beam median barrier end terminal design is very similar to the box-beam guardrail end terminal design and based on the same telescoping tube concept. The telescoping tube terminal concept involves placing an oversized outer tube on the end of the box-beam barrier that telescopes over the standard box-beam rail element. An impact head is placed in front of the outer tube to capture the striking vehicle. Energy absorbers are placed inside the outer tube to attenuate the energy of the impacting vehicle and provide a controlled deceleration to the impacting vehicle. The terminal is designed with an adequate anchorage system and a mechanism to transmit tensile forces from the end terminal to the barrier length-of-need to provide tensile capacity for the box-beam barrier to successfully redirect an vehicle impacting the side of the barrier. Thus, the end terminal system is capable of transmitting high tensile loads while having very low compressive strength.

During end-on or low-angle impacts, the impact head would capture the impacting vehicle and the outer tube would telescope back over the box-beam rail element. Energy absorbers, placed inside the outer tube, would then be crushed as the system telescopes down, thereby providing a controlled deceleration for impacting vehicles. For head-on impacts at higher angles, the system would initially capture the impacting vehicle. However, as the terminal telescopes back, the impacting vehicle would push the barrier end to the side. Eventually, lateral loads in the terminal would become sufficient to bend the outer rail element and allow the vehicle to pass behind the barrier. For side impacts, the terminal would function just like a standard box-beam barrier to contain and redirect the impacting vehicles.

3.2 Median Barrier End Terminal Design

The box-beam median barrier end terminal design was adapted from the box-beam guardrail end terminal design and shares most of the major components. By using a similar design and the same major components for both end terminal designs, this would simplify the installation and maintenance requirements for the Department, such as inventory of repair parts and training of construction and maintenance personnel. Figure 1 shows details of the box-beam median barrier end terminal design that was successfully crash tested. Details of the box-beam guardrail, median barrier, and the end terminal designs as adopted by the Wyoming DOT in its standard drawings are shown in Appendix

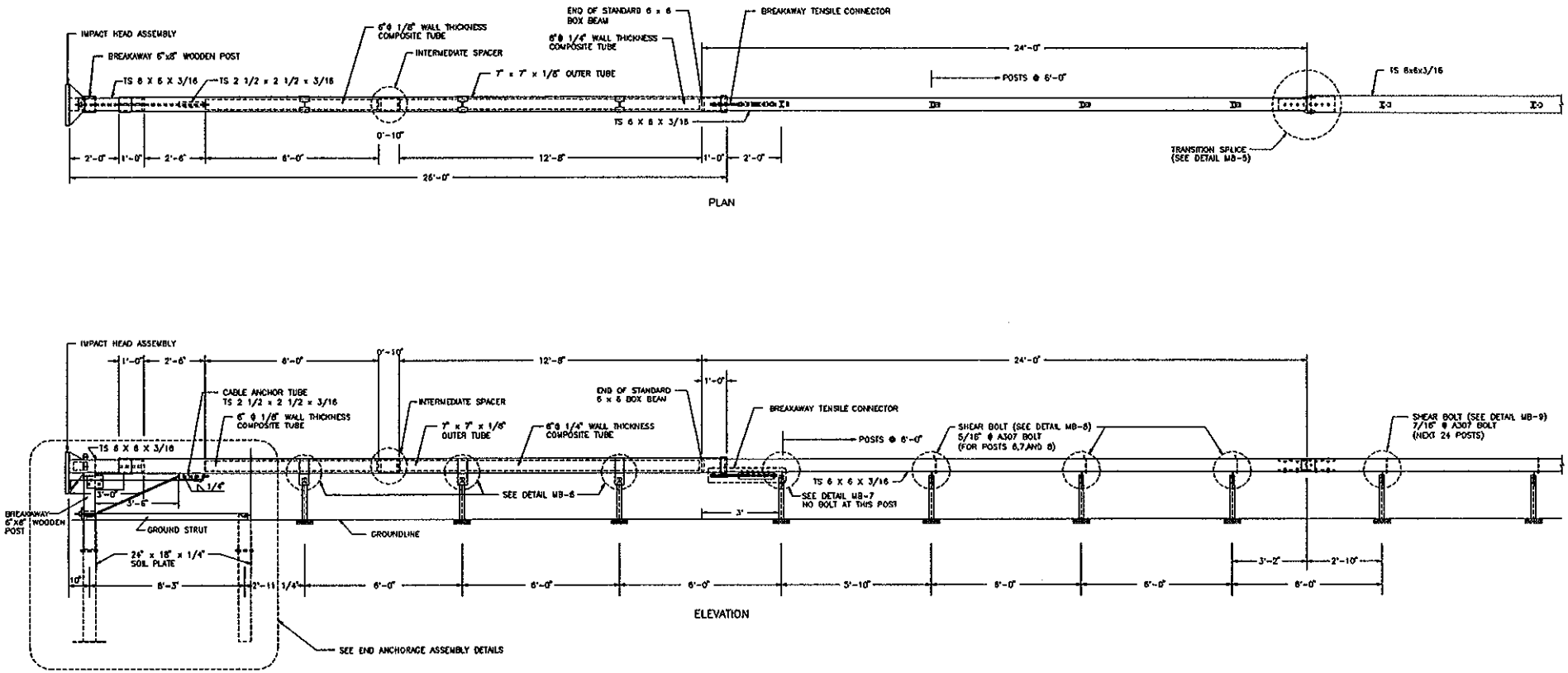
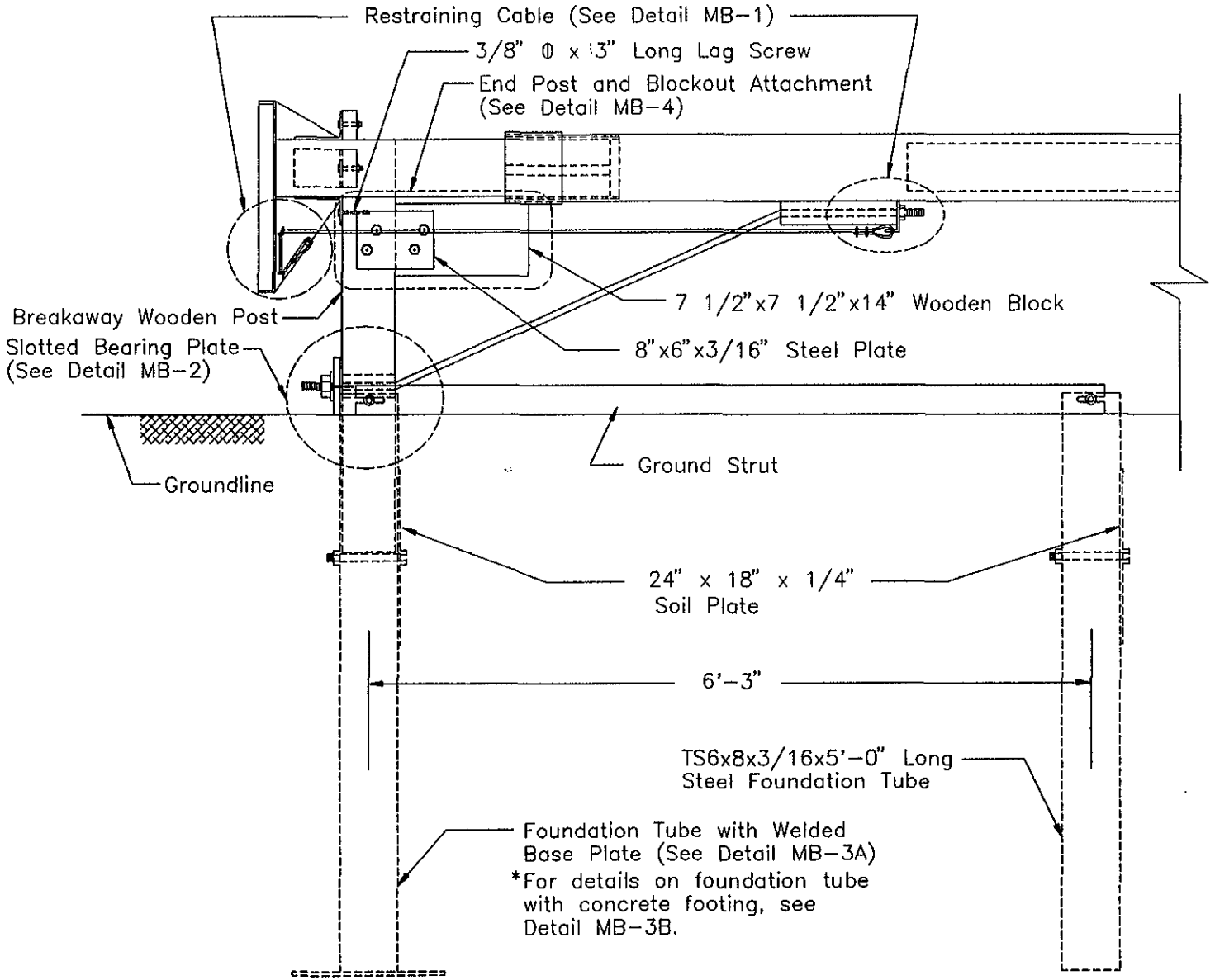
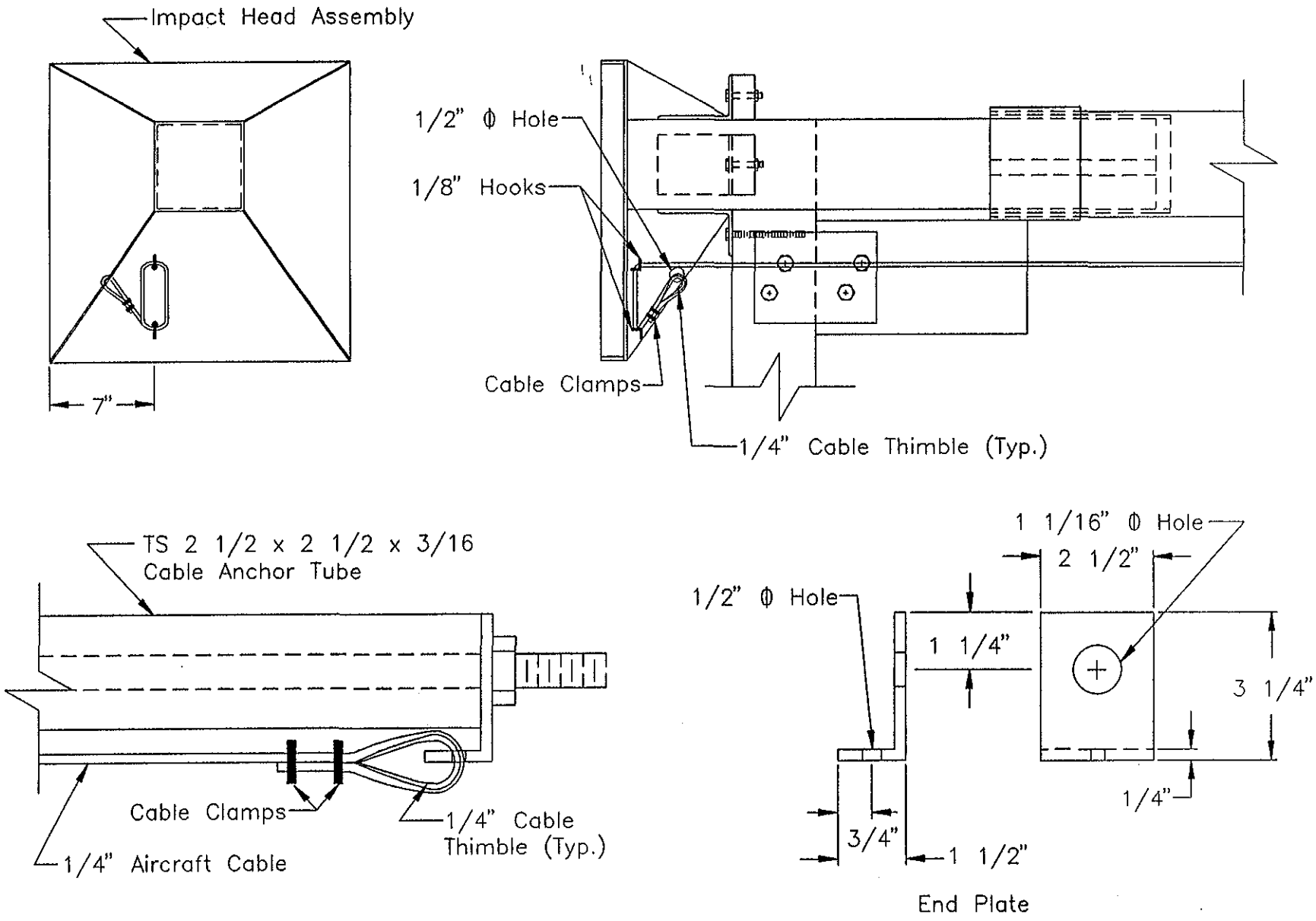


Figure 1. Schematic of box-beam median barrier end terminal.



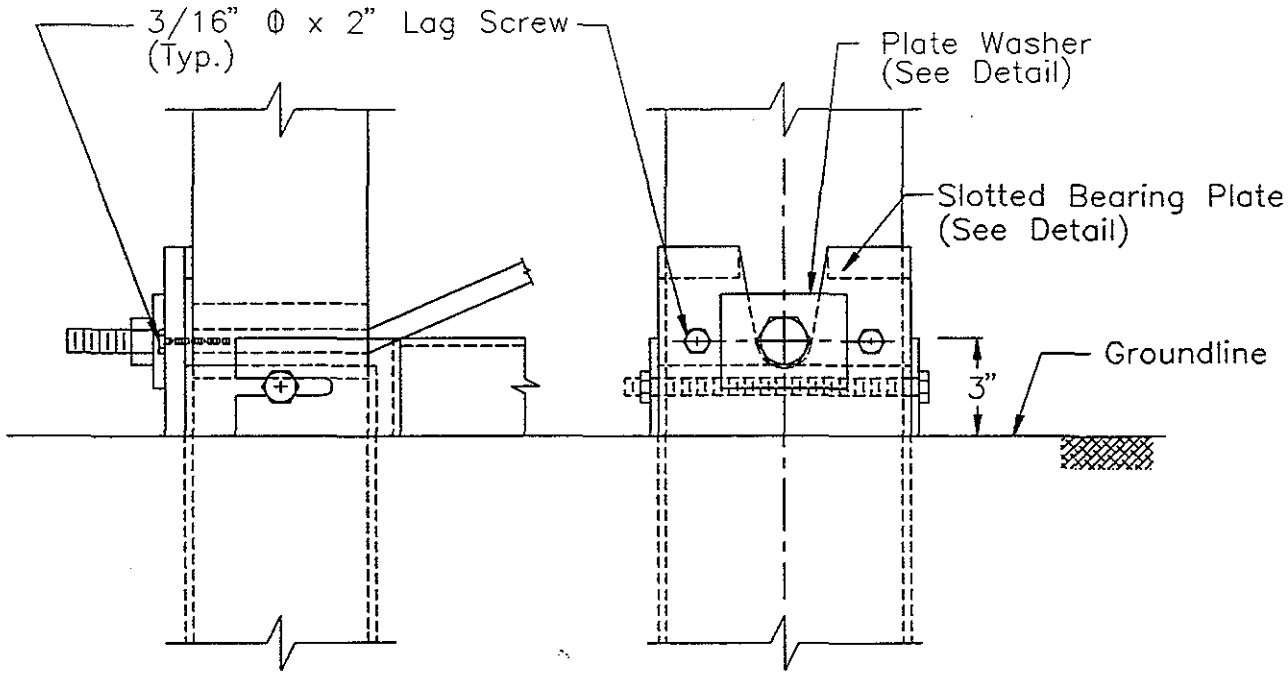
END ANCHORAGE ASSEMBLY

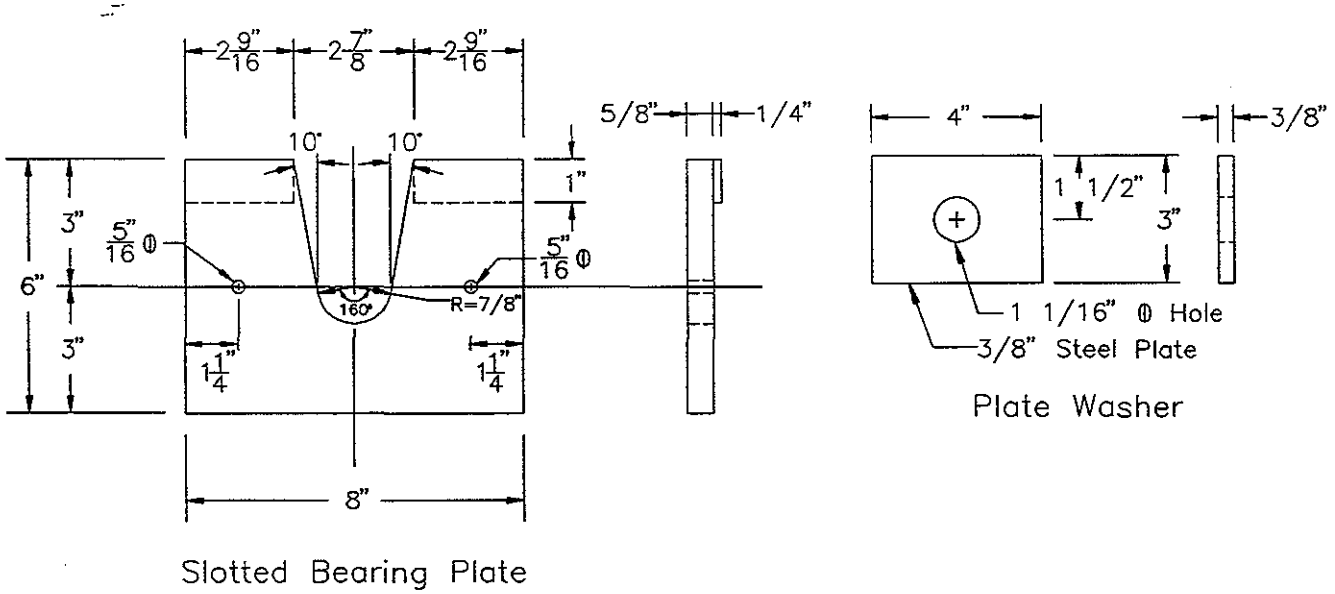
Figure 1. Schematic of box-beam median barrier end terminal (continued).



DETAIL MB–1
RESTRAINING CABLE

Figure 1. Schematic of box-beam median barrier end terminal (continued).

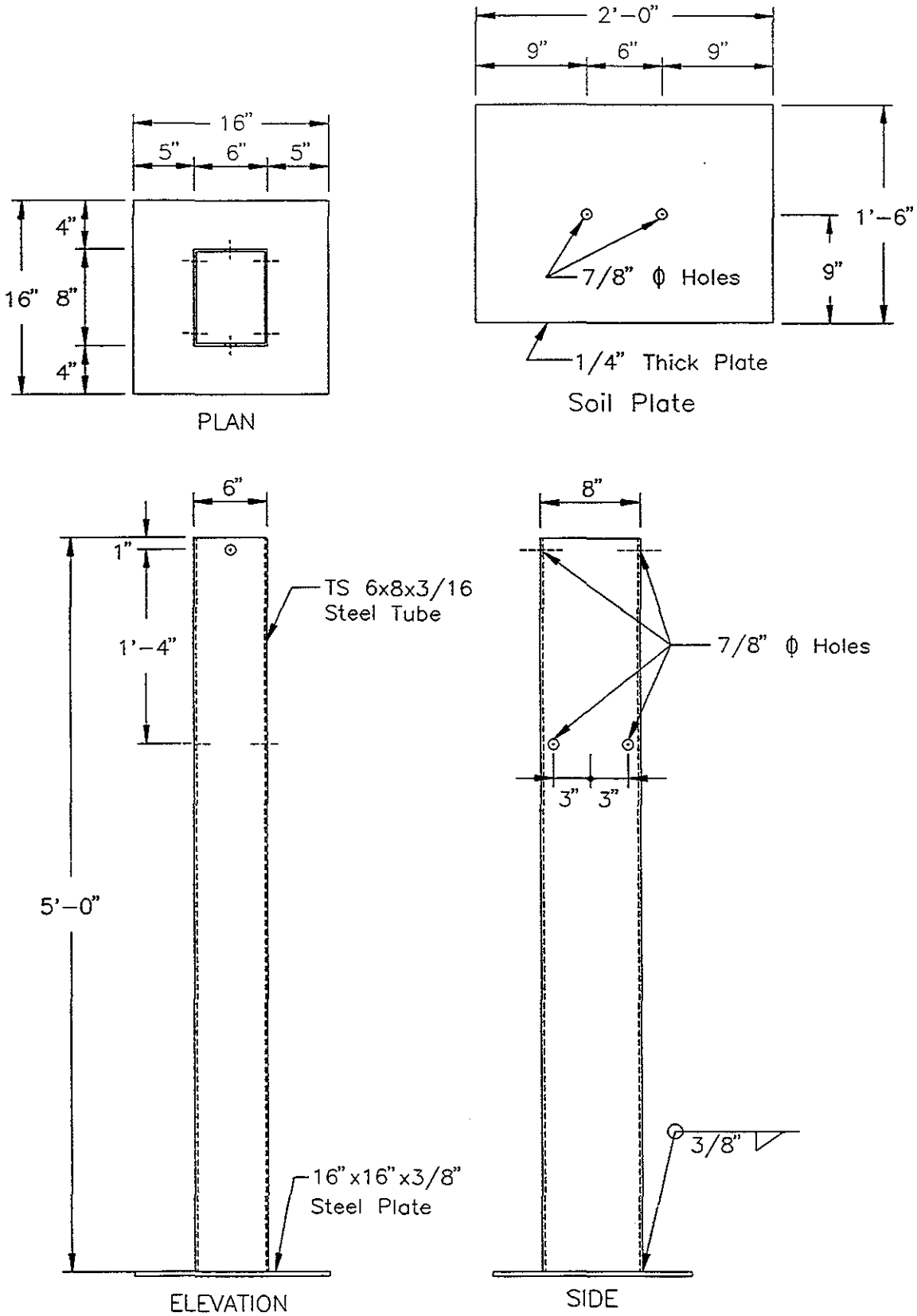




Slotted Bearing Plate

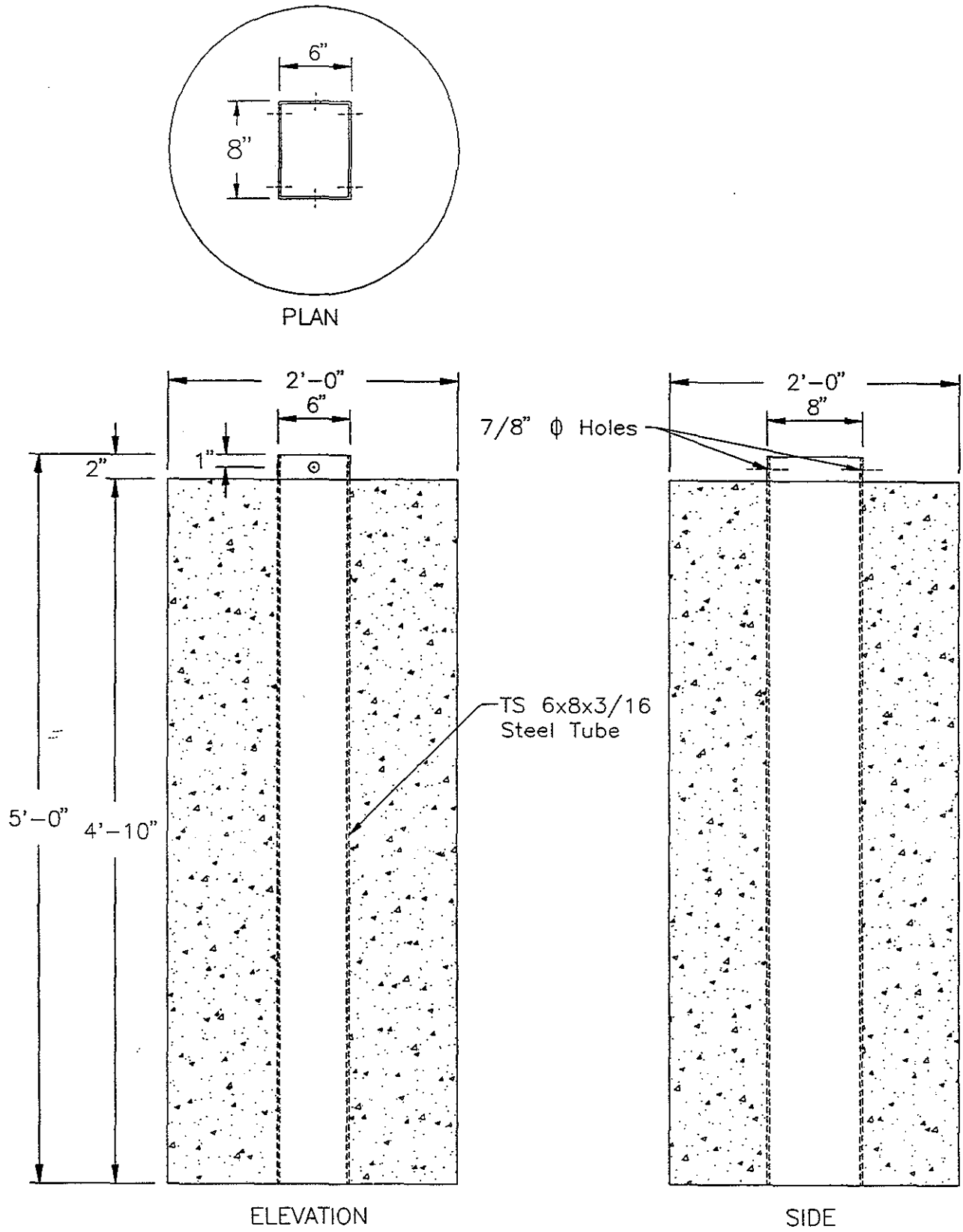
DETAIL MB–2
SLOTTED BEARING PLATE

Figure 1. Schematic of box-beam median barrier end terminal (continued).



DETAIL MB-3A
FOUNDATION TUBE WITH WELDED BASE PLATE

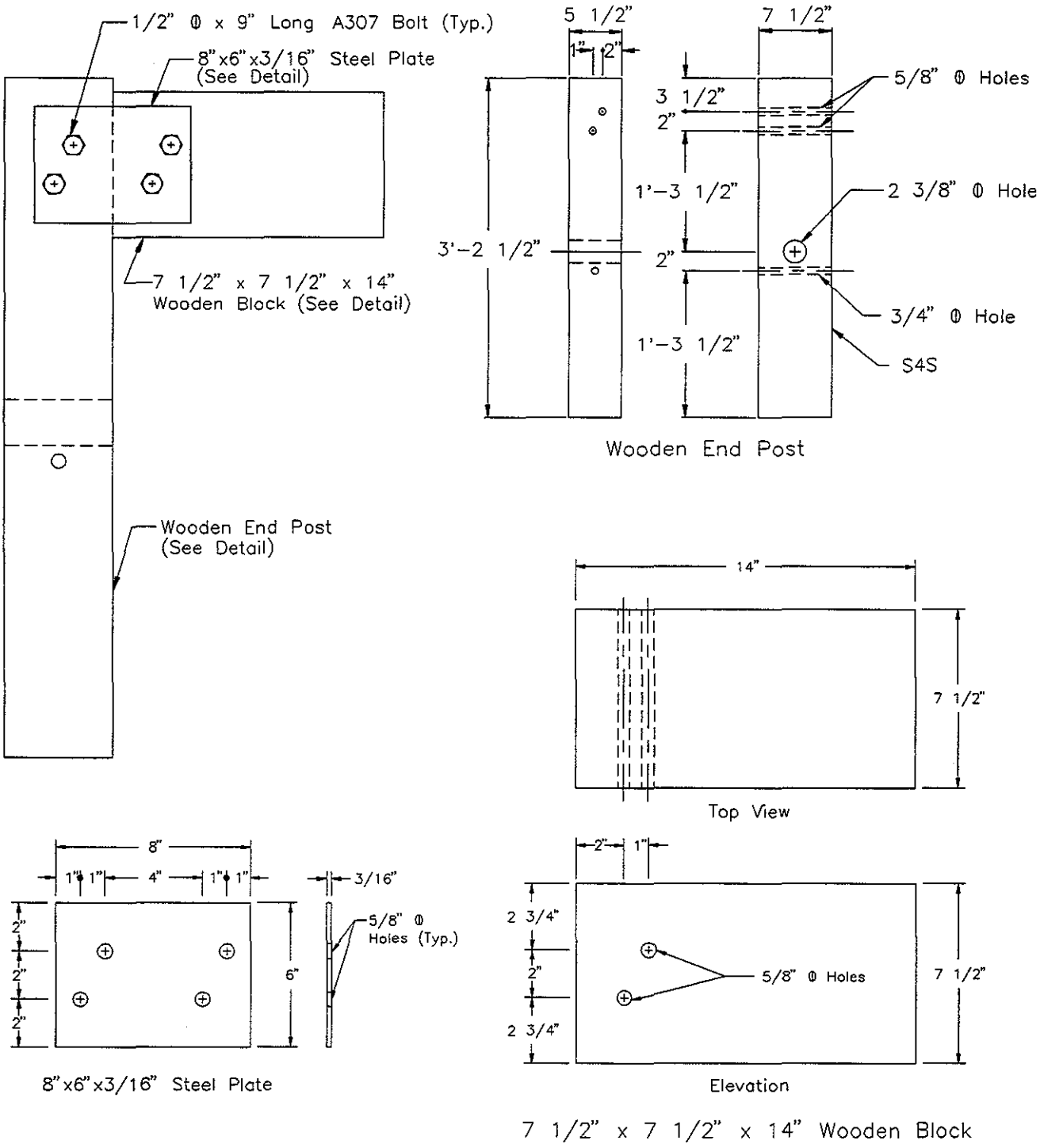
Figure 1. Schematic of box-beam median barrier end terminal (continued).



DETAIL MB-3B

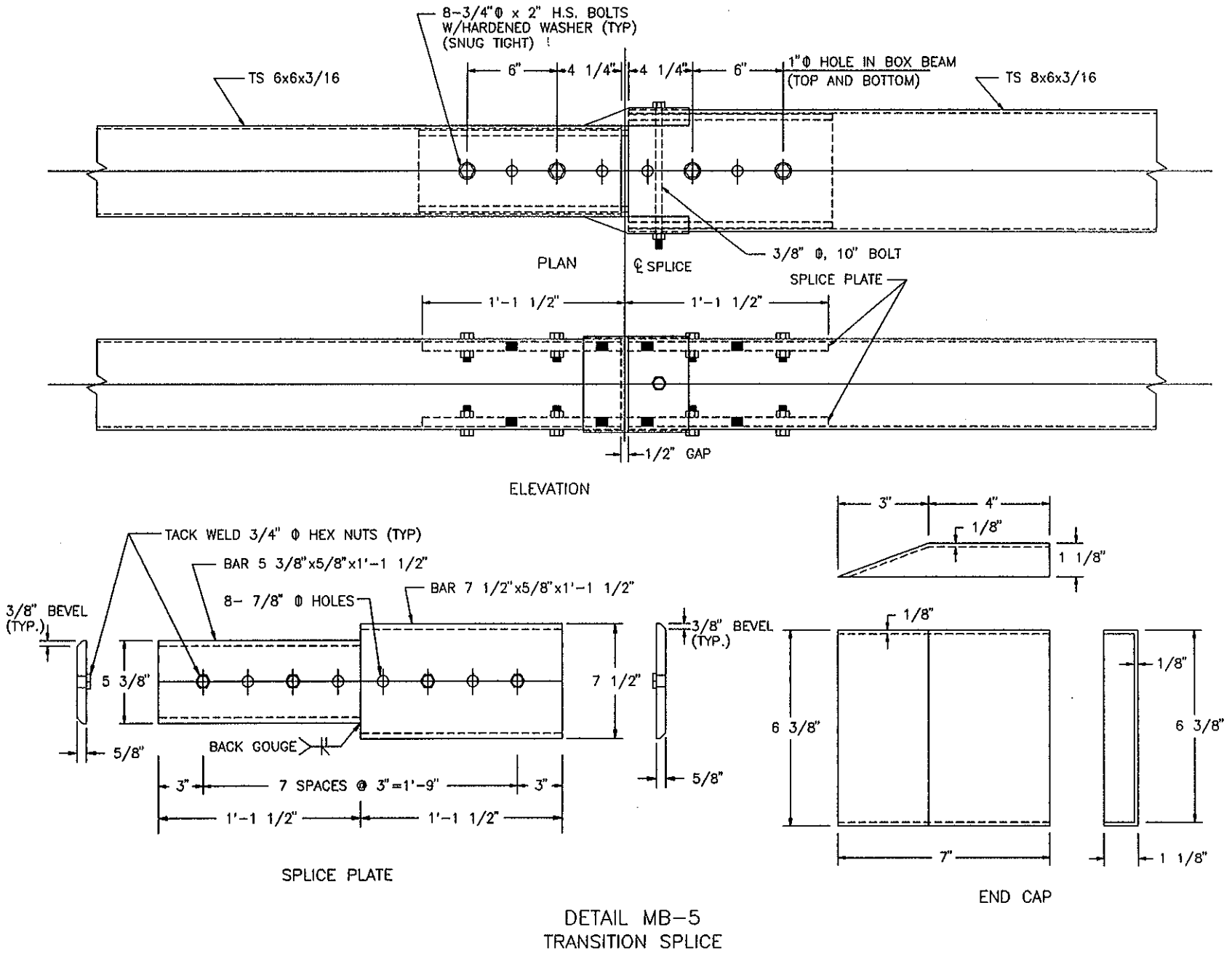
FOUNDATION TUBE WITH CONCRETE FOOTING

Figure 1. Schematic of box-beam median barrier end terminal (continued).



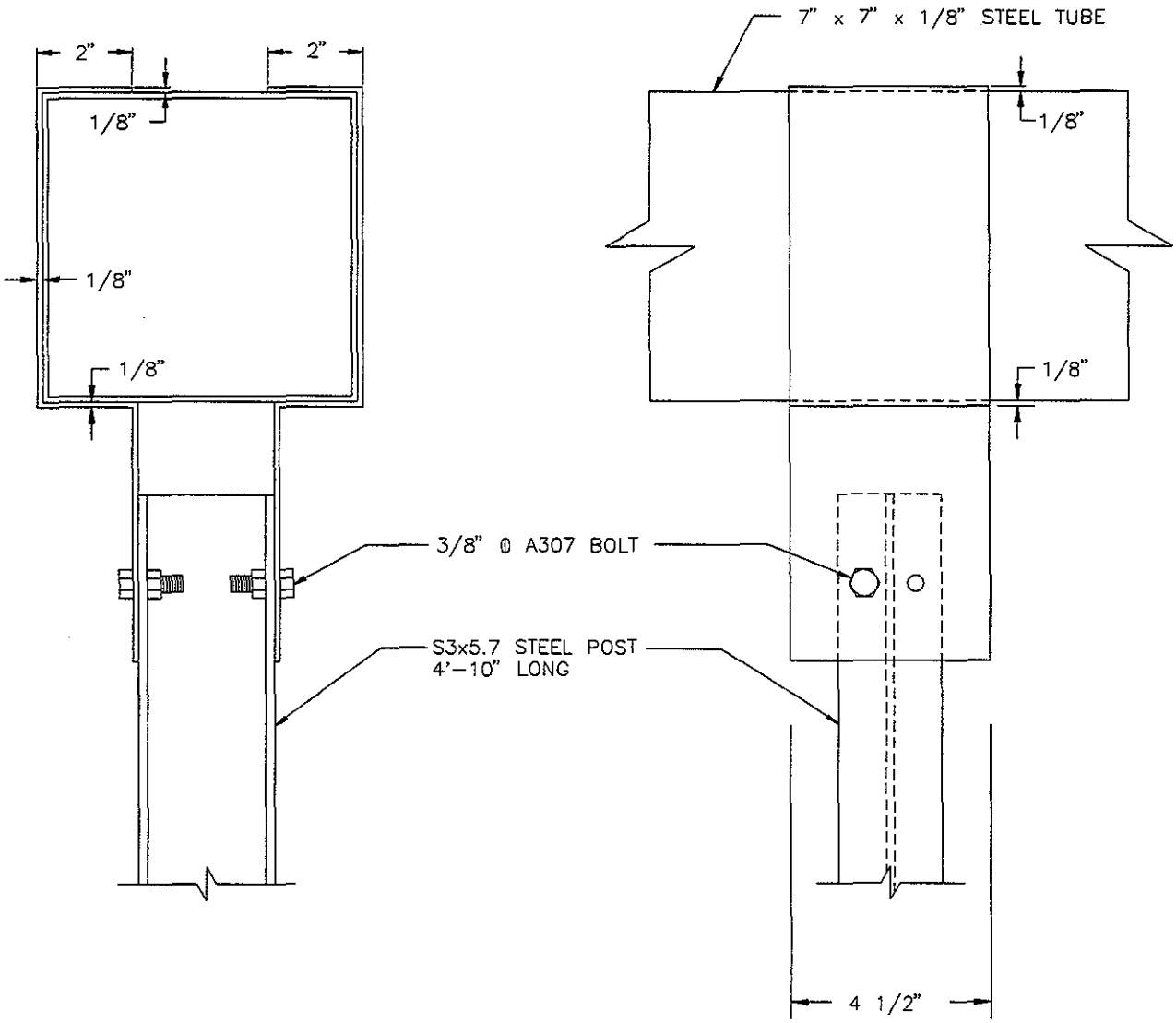
DETAIL MB-4
END POST AND BLOCKOUT ATTACHMENT

Figure 1. Schematic of box-beam median barrier end terminal (continued).



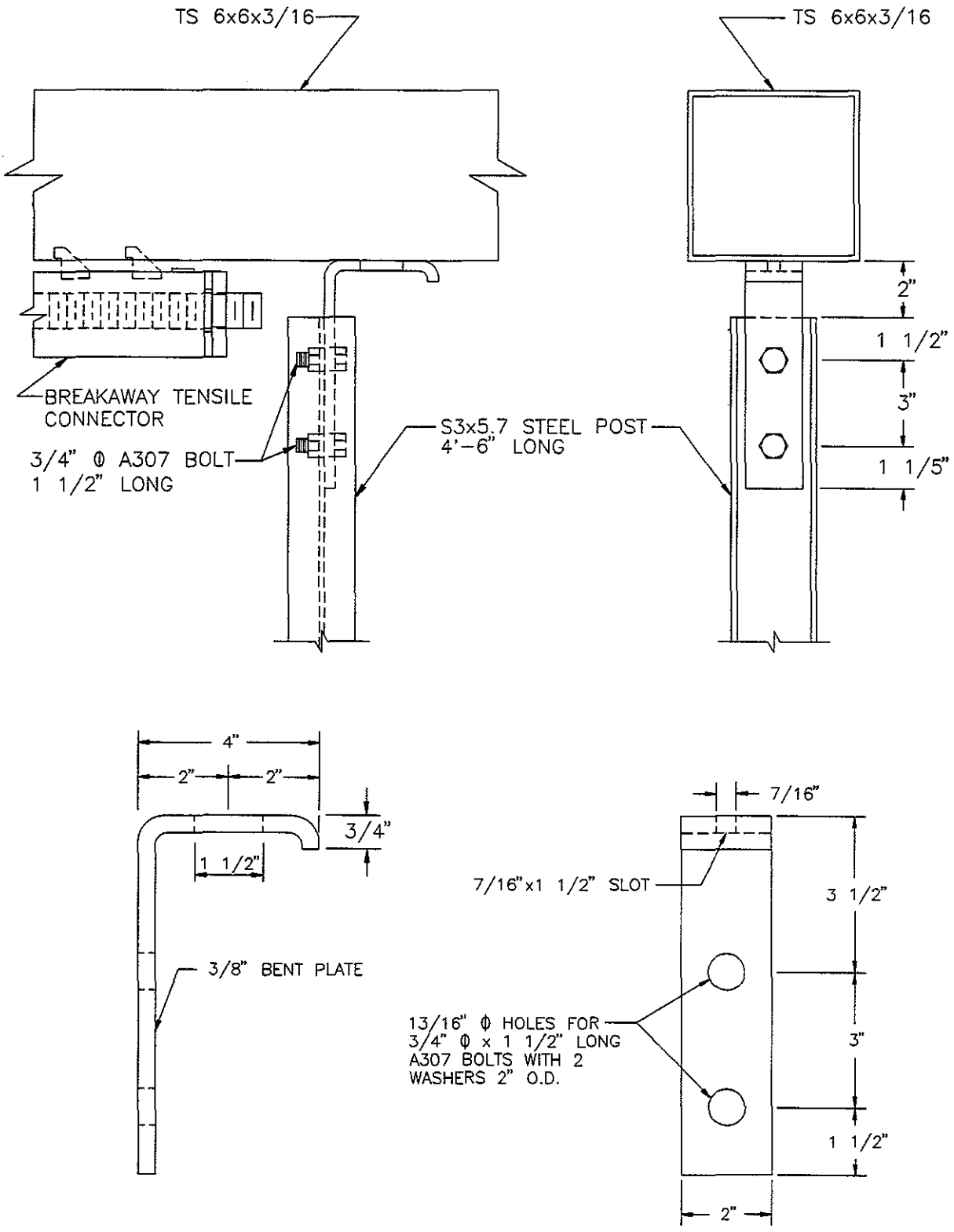
DETAIL MB-5
TRANSITION SPLICE

Figure 1. Schematic of box-beam median barrier end terminal (continued).



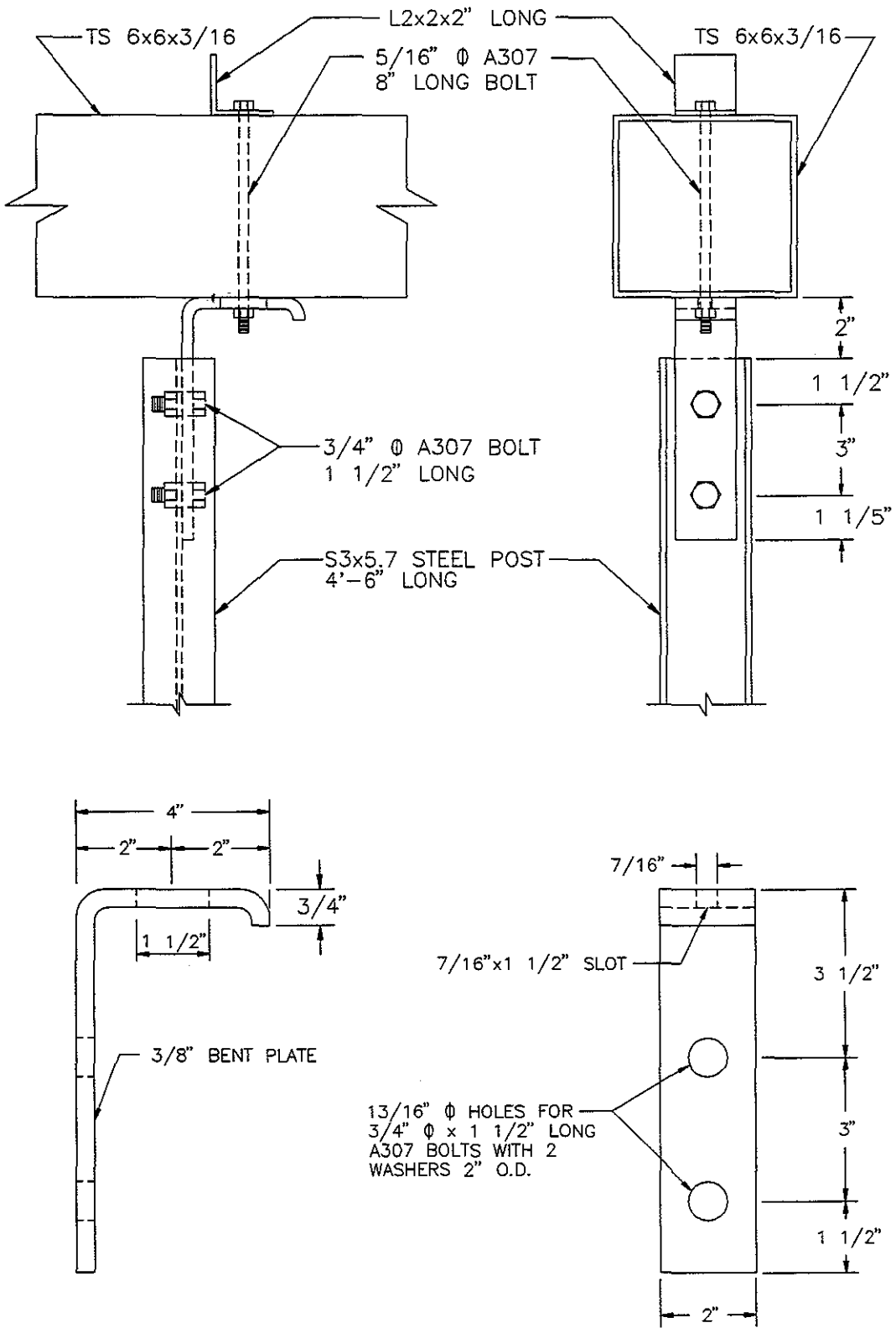
DETAIL MB-6
POST ATTACHMENT DETAIL FOR POSTS 2, 3, AND 4

Figure 1. Schematic of box-beam median barrier end terminal (continued).



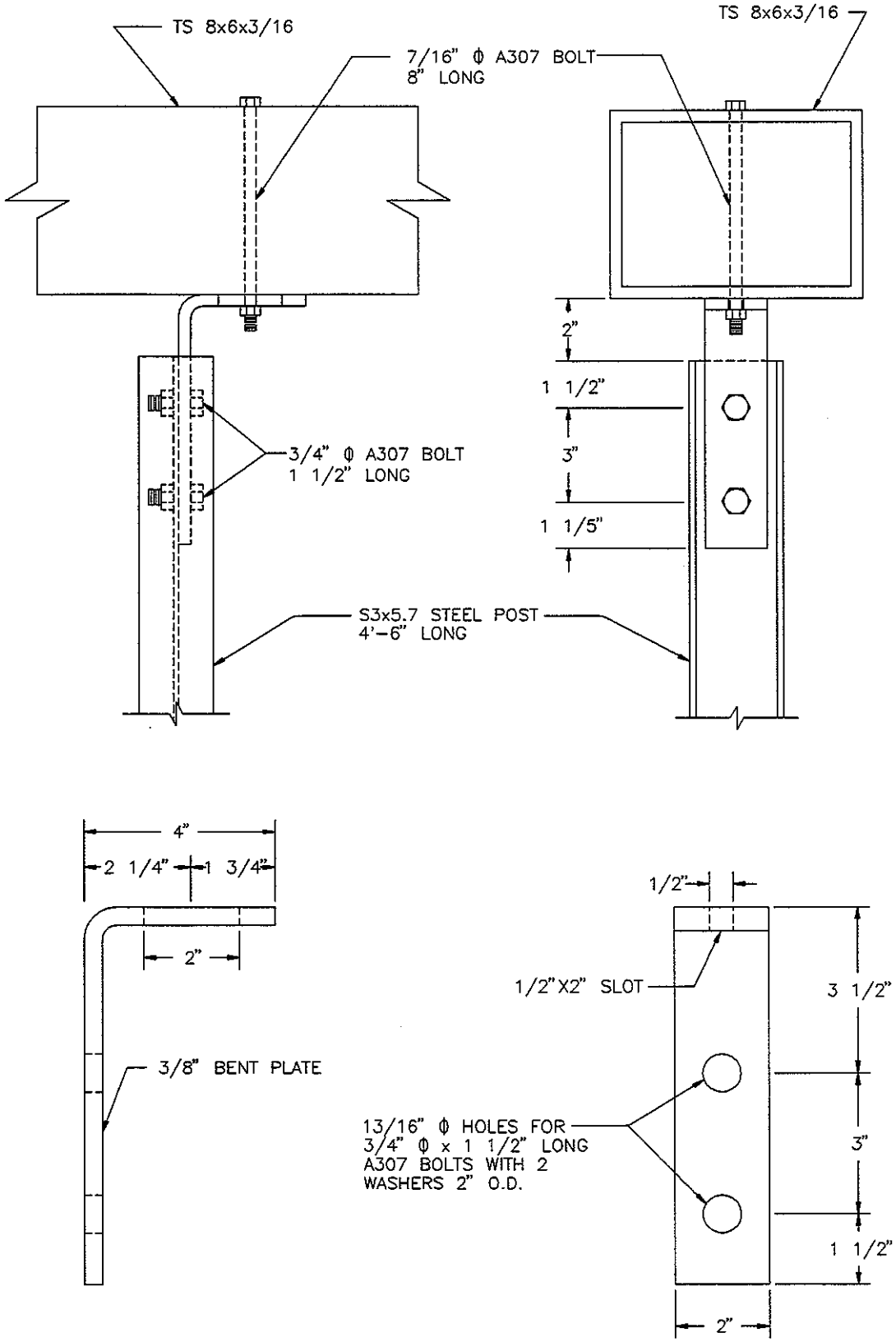
DETAIL MB-7
POST ATTACHMENT DETAIL FOR POST 5

Figure 1. Schematic of box-beam median barrier end terminal (continued).



DETAIL MB-8
POST ATTACHMENT DETAIL FOR POSTS 6, 7, AND 8

Figure 1. Schematic of box-beam median barrier end terminal (continued).



DETAIL MB-9

POST ATTACHMENT DETAIL FOR POSTS 9 THROUGH 32

Figure 1. Schematic of box-beam median barrier end terminal (continued).

A. Note that only details specific to the median barrier end terminal design are included in Figure 1. Details common to both the guardrail and median barrier end terminal designs are shown in Appendix A and not repeated in Figure 1.

The major components of the box-beam median barrier end terminal are as follows:

1. An outer tube that telescopes over a standard section of box-beam guardrail rail element;
2. An impact head assembly;
3. An end anchorage system;
4. A tensile connector between the outer tube and the standard box-beam rail element;
5. Energy absorbers; and
6. Post attachment details.

Brief descriptions of the box-beam median barrier end terminal design and the major components are presented in the following sections.

Telescoping Tubes. The outer tube is 24 ft (7.3 m) long and has outside dimensions of 7 in. x 7 in. (178 mm x 178 mm). It is specially fabricated from 1/8 in. (3.2 mm) thick sheet metal since all standard sizes of structural steel tubing large enough to encompass the standard 6 in. x 6 in. (152 mm x 152 mm) box-beam are too heavy for use with the terminal. For example, a TS 7 in. x 7 in. x 3/16 in. (178 mm x 178 mm x 4.8 mm) tube weighs approximately 17 lb/ft (25.3 kg/m) and a 24-ft (7.32-m) section would weigh over 400 lb (181 kg). Such a heavy element would cause excessive decelerations when impacted by small cars. This specially fabricated 7 in. x 7 in. x 1/8 in. (178 mm x 178 mm x 3.2 mm) A36 steel outer tube weighs approximately 310 lb (141 kg).

The tube is manufactured from two bent plates and continuously welded along two corners. Note that the original design with the guardrail end terminal uses a series of 3-in. (76.2-mm) welds spaced 6 in. (152 mm) center to center instead of a continuous weld due to concern over warping of the tube. In the fabrication of the prototype median barrier end terminal test installation, a continuous welded outer tube was successfully fabricated and used with the crash tests. It appears that continuous welding for the outer tube is a feasible alternative, which would be desirable from the standpoint of maintenance since it would eliminate the concern over moisture getting inside the outer

tube from the skip welds and would reduce the potential of damage to the outer tube from low-speed or nuisance impacts.

Each end of the tube is strengthened with outer collars to reduce the potential for damage to the outer tube during low-speed impacts. The upstream end of the outer tube incorporates a 6 in. (152 mm) wide, 1/4 in. (6.4 mm) thick A36 steel collar, while the downstream end is constructed with a similar collar that is 2 in. (50.8 mm) wide.

The outer tube telescopes over a 24 ft (7.3 m) long standard section of TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) A500 Grade B box-beam guardrail rail element. The upstream end of the standard box-beam inner tube is enlarged to provide a closer fit inside the outer tube by welding 1 in. x 1/4 in. (25.4 mm x 6.4 mm) steel straps to the outside of the box beam on all four sides at the end and at 1 ft (30.4 cm) downstream from the end. This reduces the clearance between the inner and outer tubes to approximately 1/8 in. (3.2 mm) on all sides. If the inner tube is inserted 1 ft (0.31 m) into the outer tube, this level of tolerance will allow only a 1.2-degree misalignment between the two tubes. Also, an end cap, made from 1/8 in. (3.2 mm) thick steel plate, is welded to the end of the standard box-beam section to serve as a piston for crushing the energy absorbers placed inside the outer tube.

Impact Head Assembly. The impact head assembly, as shown in Sheet 7 of Appendix A, is designed along the lines of the ET-2000 impact head and weighs approximately 125 lb (57 kg). The impact plate is constructed with a 20 in. x 20 in. x 3/8 in. (508 mm x 508 mm x 9.5 mm) A36 steel plate and incorporated 1-1/2 in. x 1/4 in. (38.1 mm x 6.4 mm) A36 steel straps welded on the perimeter of the plate to provide a mechanical interlock with impacting vehicles. The impact plate is attached using 3/8 in. (9.5 mm) thick A36 steel gussets to a 3 ft (0.91 m) long section of standard TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) A500 grade B steel tube normally used in box-beam guardrails. The end of the 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) tube is enlarged in a fashion similar to that of the upstream end of the standard box-beam section to provide a closer fit inside the outer tube and to minimize the possibility of rotation within the outer tube. However, instead of using a second spacer 12 in. (305 mm) from the end, 1 in. x 1/4 in. (25.4 mm x 6.4 mm) steel straps are welded longitudinally along the last 12 in. (305 mm) of the box-beam section on all four sides to prevent the possibility of the second spacer snagging on the end of the outer tube.

Preliminary testing indicated that the gusset plates on the impact head could cut through the end of the outer tube, causing severe damage, even under relatively modest impact conditions. Therefore, steel angles with 1-1/2 in. (38.1 mm) thick rubber pads are welded to the sides of the TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) tube to prevent direct contact between the gusset plates and the outer tube. The rubber pads both reduce the impact forces transmitted to the vehicle when the impact head contacts the outer tube and the damage to the outer tube during low and moderate speed impacts.

A restraining cable is provided to minimize the potential for the impact head to be thrown a long distance in reverse direction impacts which could potentially pose a hazard for adjacent traffic and other bystanders, such as pedestrians. The restraining cable is made from 1/4-in. (6.4-mm) diameter aircraft type cable and is approximately 9 ft (2.74 m) in length. One end of the restraining cable is attached to the impact head through a hole drilled in one of the gusset plates and the other end is attached to the plate washer used for the downstream end of the cable anchor through a hole drilled in the plate washer. The cable ends are secured in place with cable clamps and sleeves are used to minimize the potential for the cable to be cut by the sharp edges of the holes for attachment. Note that the length of the restraining cable is approximately 9 ft (2.74 m) while the actual distance between the two attachment points is roughly 5 ft-9 in. (1.75 m). The additional cable length provides the needed slack for the impact head to clear the outer tube since the impact head is inserted 1 ft (30.5 cm) into the outer tube. To avoid the restraining cable hanging down because of the extra length, two hooks are provided on the back of the impact plate for winding the cable to take up the slack. Details of the restraining cable are shown in Detail MB-1 of Figure 1.

End Anchorage System. The end anchorage system is similar to that of the breakaway cable terminal (BCT). The impact head is attached to a 5-1/2 in. x 7-1/2 in. (140 mm x 191 mm) breakaway wood post inserted into a 5-ft (1.52-m) long, 6 in. x 8 in. (152 mm x 203 mm) steel foundation tube. The wood post is weakened with a 2-3/4-in. (69.9-mm) diameter hole at the base. A BCT type cable anchorage assembly is attached to the outer tube using a TS 2-1/2 in. x 2-1/2 in. x 3/16 in. (63.5 mm x 63.5 mm x 4.8 mm) steel tube welded to the outer surface. Note that the anchorage of the cable attachment to the outer tube is welded and not bolted on since protrusion of the bolts inside the outer tube would interfere with the energy absorber. The cable was anchored to the wooden end post and the foundation tube through a hole in the base of the post.

A slotted bearing plate, as shown in Detail MB-2 of Figure 1, is used to anchor the cable to the wooden end post. The standard bearing plate used with the BCT cable assembly does not allow the bearing plate to separate from the cable after the post is broken from impact by the vehicle. In the first small car reverse direction test (test no. 7202-6), the cable anchor bearing plate, after releasing from the wooden end post, was thrown up underneath the vehicle and caught on the transmission housing of the vehicle. This restrained the forward movement of the vehicle on the left front, resulting in the vehicle yawing rapidly and coming to an abrupt stop. To eliminate this potential of the cable anchor bearing plate being caught or snagged on some part of the undercarriage of the vehicle, a slotted configuration is incorporated into the bearing plate so that the bearing plate would separate from the cable anchor upon breaking of the wooden end post. A 4 in. x 3 in. x 3/8 in (102 mm x 76 mm x 9.5 mm) plate washer is used with the slotted bearing plate. Also, to avoid the cable anchor bearing plate being displaced from the proper position when the cable is loosened, two 1/4-in (6.4-mm) diameter lag screws are used to attach the bearing plate to the wooden end post.

The box-beam guardrail end terminal uses a second steel foundation tube with ground channel strut to reinforce the foundation tube under the first post. However, only one wooden breakaway post is used with the first foundation tube, which also supports the impact end section of the end terminal assembly. The second foundation tube does not have a post and is used only to increase the tensile capacity of the anchorage system.

Results from the first large car length-of-need crash test (test no. 7202-8) indicated that this anchorage assembly does not have adequate anchorage capacity for the box-beam median barrier end terminal. The end post foundation tube was pulled out of the ground in that test, resulting in penetration of the barrier by the impacting vehicle. A revised anchorage design was therefore developed to increase the anchorage capacity of the end terminal. Two alternate anchorage designs were developed as follows:

1. Weld a base plate to the bottom of the end post foundation tube to increase the soil bearing capacity of the foundation tube, and
2. Embed the end post foundation tube in a concrete footing.

The base plate alternate anchorage assembly design, shown in Detail MB-3A of Figure 1, is the same as that for the box-beam guardrail end terminal except for the addition of a 16 in. x 16 in.

x 3/8 in. (406 mm x 406 mm x 9.5 mm) base plate welded to the bottom of the end post foundation tube. The base plate, with the soil overburden, would greatly increase the force required to pull the foundation tube out of the ground. Otherwise, the anchorage assembly still uses two foundation tubes with a connecting ground channel strut and no post in the second foundation tube. The base plate alternate design was incorporated in the test installation since it was considered the weaker of the two alternate anchorage designs. The rationale is that, if the weaker base plate anchorage design performs satisfactorily, the stronger concrete footing design would even work better.

The concrete footing alternate design, shown in Detail MB-3B of Figure 1, uses a 24-in. (610-mm) diameter, 5 ft (1.52 m) deep concrete footing around the end post foundation tube. Due to the size of the concrete footing, the second foundation tube with the connecting ground channel strut are no longer considered necessary and are deleted from the design. The cost for pouring the concrete footing is therefore partially offset by the elimination of the second foundation tube and the ground channel strut.

In the first small car reverse direction test (test no. 7202-6), the left front wheel of the vehicle was wedged underneath the anchor cable prior to breaking of the wooden end post, resulting in very high deceleration rate on the vehicle. To facilitate breaking of the wooden end post prior to the front wheel of the vehicle being wedged underneath the anchor cable, a standard 6 in. x 8 in. (152 mm x 203 mm) x 14 in. long (356 mm) wooden blockout was attached to the top of the wooden end post . The wooden blockout is bolted to the top of the wooden end post with two steel brackets, details of which are shown in Detail MB-4 of Figure 1.

Breakaway Tensile Connector. The outer tube transmits tension to the rest of the box-beam rail through a breakaway tensile connector, similar in design to that used with the ET-2000 guardrail terminal, as shown in Sheet 7 of Appendix A. Six lugs with teeth in one direction and sloped surfaces in the other direction were welded to the top of a 3 in. x 2 in. x 3/16 in (76.2 mm x 50.8 mm x 4.8 mm) x 16-3/4 in. (435 mm) long structural tubing. Corresponding holes were cut on the bottom of the TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) box beam for the lugs to engage, as shown in Sheet 6 of Appendix A. The detachable anchor mechanism was then attached to the outer tube with a 1-1/4-in. (31.8-mm) diameter Grade 5 all-thread rod and a 6 in. (152 mm) long, 2 in. x 2 in. x 3/16 in. (50.8 mm x 50.8 mm x 4.8 mm) structural tube welded to the bottom of the outer tube. Lugs on the detachable anchor mechanism is designed to release from the holes in the box-beam rail when the device is loaded in compression during end-on impacts. During side impacts, the

anchor mechanism is loaded in tension and the steel lugs do not release from the box-beam rail, thereby preventing the two telescoping beams from becoming separated.

The TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) box-beam guardrail rail element is then connected to the standard 6 in. x 8 in. x 1/4 in. (152 mm x 203 mm x 6.4 mm) box-beam median barrier rail element using special splice plates, as shown in Detail MB-5 of Figure 1. Since there is difference of 2 in. (50.8 mm) between the widths of the box-beam guardrail and median barrier rail elements, the median barrier rail element protrudes out 1 in. (25.4 mm) on either side of the guardrail rail element. Special end caps, also shown in Detail MB-5 of Figure 1, are bolted to the median barrier rail element to cover the protrusions and minimize the potential for snagging by impacting vehicles.

Energy Absorber. Pultruded fiber reinforced plastic (FRP) structural tubes are used as the energy absorbers for both the box-beam guardrail and median barrier end terminal designs. Two stages of energy absorbing elements are used in the terminal design. The first stage is intended for impacts by small vehicles, i.e., 1,800-lb (817-kg) passenger cars, and has a lower level of stiffness to provide an acceptable level of deceleration for the smaller vehicles. The second stage has a higher level of stiffness in order to handle impacts by larger and heavier vehicles, i.e., 4,500-lb (2,041-kg) passenger cars or pickup trucks. A 6 ft (1.83 m) long, 6-in. (152-mm) diameter composite tube with a 1/8-in. (3.2-mm) wall thickness was selected for the first-stage energy attenuation. Both ends of the composite tube are cut into a tulip-like shape, each approximately 6 in. (152 mm) in length, as shown in Sheet 6 of Appendix A. This provides 12 in. (305 mm) of crush with reduced stiffness at initial impact to minimize the impulse associated with initiation of crush of the composite tube. Based on results of static and dynamic testing, the expected stiffness of the 6-in. (152-mm) diameter, 1/8-in. (3.2-mm) thick side-wall composite tube is approximately 18 kips per foot (263 kN/m).

The second-stage energy attenuation is provided by a 12 ft-8 in. (3.86 m) long, 6-in. (152-mm) diameter composite tube with a 1/4-in. (6.4-mm) wall thickness, also shown in Sheet 6 of Appendix A. Again, both ends of the composite tube are cut into a tulip shape, approximately 4 in. (102 mm) in length, for proper initiation of the crush. The expected stiffness of this 6-in. (152-mm) diameter, 1/4-in. (6.4-mm) thick side-wall composite tube is approximately 35 kips per foot (509 kN/m).

An intermediate spacer is used to separate the two different thickness composite tubes. The spacer, as illustrated in Sheet 6 of Appendix A, consists of a 10 in. (254 mm) long section of standard

6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) box beam. End caps made from 1/8 in. (3.2 mm) thick steel plate are welded to both ends of the box-beam section. Also, steel spacer straps, 1 in. x 1/4 in. (25.4 mm x 6.4 mm), are welded to the box beam at both ends to reduce the amount of free play inside the outer tube.

Post Attachment Details. Except for the breakaway wooden end post, the other posts in the end terminal section are S3x5.7 structural steel posts. The standard box-beam median barrier uses a slot and paddle connection between the rail element and the posts and the standard box-beam guardrail uses a post angle and through bolt connection. Neither of these two connection designs is appropriate for use with the outer tube due to the presence of the energy absorbers inside the outer tube. In order to facilitate telescoping of the outer tube over the standard box-beam rail, special shelf angles fabricated from 1/8-in. (3.2-mm) thick sheet metal plates are used with the outer tube at posts 2 through 4, as illustrated in Detail MB-6 of Figure 1. These shelf angles provide some constraint of the outer tube without the need for inserting a paddle or passing a bolt though the box beam.

The standard TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) box-beam guardrail section is not bolted to the first post downstream from the outer tube (post 5), but just rests on a post angle, in order to accommodate the location of the breakaway tensile connector and to facilitate the telescoping behavior (see Detail MB-7 of Figure 1). The next three posts (posts 6, 7, and 8) for the standard box-beam guardrail section use a post angle and through bolt connection design similar to that of the standard box-beam guardrail, as shown in Detail MB-8 of Figure 1.

The post angles have dimensions of 8 in. x 4 in. (203 mm x 102 mm), fabricated from 3/8 in. (9.5 mm) thick bent plates, and are 2 in. (51 mm) in length. The post angle is bolted to the post on the long leg of the angle using two 3/4-in. (19.1-mm) diameter, 1-1/2 in. (38.1 mm) long A307 bolts. The short leg of the angle is against the bottom of the 6 in. x 6 in. (152 mm x 152 mm) box-beam rail element and a 1/2 in. (12.7 mm) wide by 1-1/2 in. (38.1 mm) long slot is provided for bolting the rail element to the post angle with a 5/16-in. (7.9-mm) diameter, 7-1/2 in. (191 mm) long A307 shear bolt. Note that the post angle should be so orientated that the end of the outer tube would contact the back of the long leg of the angle as the outer tube telescopes backward during head-on impacts. A 3/4 in. (19.1 mm) long lip is provided on the end of the short leg of the angle to eliminate the potential of the outer tube wedging on the short leg of the angle if the post angle is oriented in the wrong direction.

A small L2 in. x 2 in. (50.8 mm x 50.8 mm) x 2 in. (50.8 mm) long reflective angle was attached to the bolt at the top of the box beam to facilitate consistent shearing of the bolted connections during head-on impacts. Note that the reflective angle should be so orientated that the end of the outer tube should contact the short leg of the angle as the outer tube telescopes backward during head-on impacts, again to eliminate the potential of the outer tube wedging on the leg of the angle .

In the second large car length-of-need strength test (test no. 7202-9), the vehicle was successfully redirected by the end terminal and physically separated from the barrier. However, the median barrier rail element came off the paddles and separated from the posts ahead of the vehicle trajectory due to the lateral and longitudinal movement of the rail element. The rail element then dropped to the ground under its own weight after the vehicle disengaged from the rail element. Shortly after the separation, the vehicle turned back toward the barrier due to damage to the front wheel and impacted the barrier a second time. Since the rail element was lying on the ground, the vehicle climbed over the rail element to go behind the barrier. Also, the separation of the rail element from the posts ahead of the vehicle trajectory effectively reduced the lateral stiffness of the median barrier since the posts were not engaged in resisting the lateral force of the impacting vehicle. It appears that this may be a problem inherent in the design of the connection between the rail element and the post of the median barrier itself and not necessarily related to the end terminal design. Nevertheless, this problem had to be fixed to eliminate the potential for future occurrence.

A more positive connection using a post angle and through bolt, similar to that used with the standard TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) box-beam guardrail section at posts 6 through 8, was incorporated into the design for the first several sections of the TS 6 in. x 8 in. x 1/4 in. (152 mm x 203 mm x 6.4 mm) box-beam median barrier rail element. The positive connections between the rail element and the posts would minimize the number of posts separating from the rail element ahead of the vehicle trajectory, which in turn would minimize the potential for an impacting vehicle to override the rail element and go behind the barrier in a secondary impact since the rail element would not have fallen and be lying on the ground ahead of the vehicle trajectory. Also, the positive connection would assure that the posts are brought into play to assist the rail element in resisting the lateral force of the impacting vehicle and maintain the lateral stiffness of the median barrier.

The connection design, as shown in Detail MB-9 of Figure 1, consists of a 8 in. x 4 in. (203 mm x 102 mm) post angle fabricated from a 3/8-in. (9.5 mm) thick bent plate, and is 2 in. (51 mm) in length. The post angle is bolted to the post on the long leg of the angle using two 3/4-in. (19.1-mm) diameter, 1-1/2 in. (38.1 mm) long A307 bolts. The short leg of the angle is against the bottom of the 6 in. x 8 in. (152 mm x 203 mm) box-beam rail element and a 1/2 in. (12.7 mm) wide by 2 in. (51 mm) long slot is provided for bolting the rail element to the post angle with a 7/16-in. (11.1-mm) diameter, 7-1/2 in. (191 mm) long A307 bolt. The size of the bolt is so chosen such that the force required to shear the bolt is comparable to that required to yield the post. This would make full use of the post strength while still allowing the post to separate from the rail element, thus minimizing the potential of reducing the effective height of the rail element due to excessive bending of the posts. However, based on results of the third large car length-of-need strength test (test no. 7202-10), it appears that the 7/16-in. (11.1-mm) diameter bolt is stronger than needed and a 3/8-in (9.5-mm) diameter A307 bolt would have been adequate.

This positive connection design was used for the entire 144 ft (43.9 m) of median barrier length-of-need in the test installation for the third large car length-of-need strength test (test no. 7202-10). However, based on the results of the test, it appears that this positive connection design is required only for a length of 54 ft (16.5 m), or the first three 18-ft (5.5-m) sections, of the median barrier rail element, beyond which the standard slot-and-paddle connection can be used.

IV. RESULTS OF CRASH TESTS

As mentioned previously, a total of five crash tests were conducted under this portion of the study:

1. First small car reverse direction test. An 1,800-lb (817-kg) passenger car impacting the end terminal in the reverse direction mid-point between the nose and the beginning of length-of-need at a nominal speed and angle of 60 mi/h (96.6 km/h) and 20 degrees.
2. Repeat of small car reverse direction test.
3. First large car length-of-need strength test. A 4,500-lb (2,041-kg) passenger car impacting the end terminal at the beginning of length-of-need at a nominal speed and angle of 60 mi/h (96.6 km/h) and 25 degrees.
4. Repeat of large car length-of-need strength test.
5. Repeat of large car length-of-need strength test.

The test installation, shown in Figure 2, consists of the end terminal at the upstream end, 144 ft (43.9 m) of length-of-need of the standard box-beam median barrier, and a sloped anchor on the downstream end. Detailed descriptions of these five crash tests are presented as follows.

4.1 First Small Car Reverse Direction Test (Test No. 472020-6)

The first test involved an 1,800-lb (817-kg) passenger car impacting the end terminal in the reverse direction approximately 8 ft-1 in. (2.5 m) downstream of the nose, which is mid-point between the nose and the beginning of length-of-need, i.e., post 3 or 16 ft-2 in. (4.9 m) downstream from the nose, at a nominal speed and angle of 60 mi/h (96.6 km/h) and 20 degrees. The objective of the test is to evaluate the potential for the impacting vehicle to snag on the cable anchor before breaking off the end post in a reverse direction impact. Photographs of the installation are shown in Figures 3 and 4.

A 1988 Yugo GVL (shown in Figures 5 and 6) was used for the test. Test inertia mass or empty weight of the vehicle was 1,800 lb (816 kg) and the gross static mass or test weight was 1,969 lb (893 kg), including a restrained 50th percentile male anthropomorphic dummy placed in the driver's position. The heights to the upper and lower edges of the vehicle bumper were 19.3 in. (489 mm)

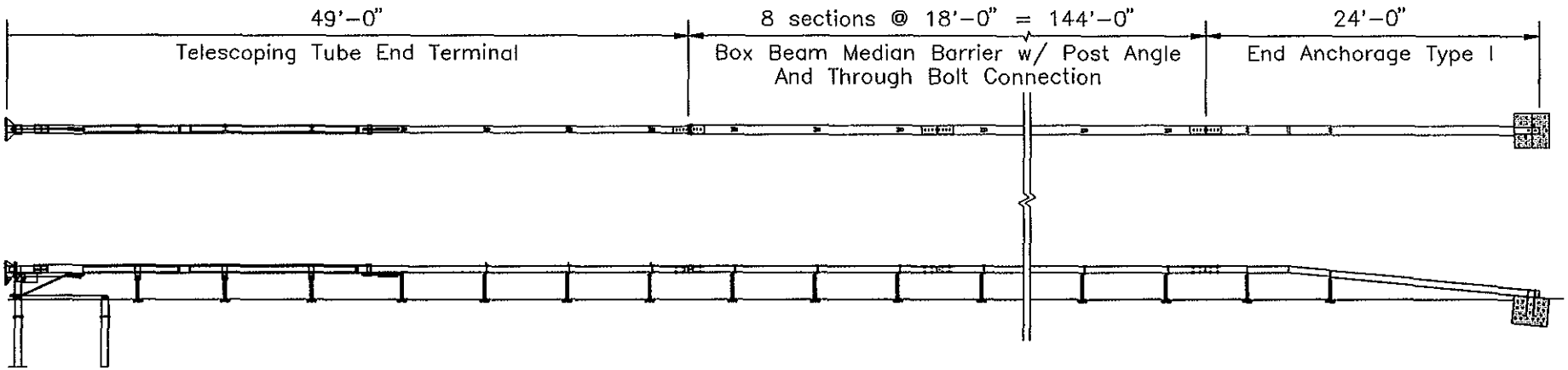
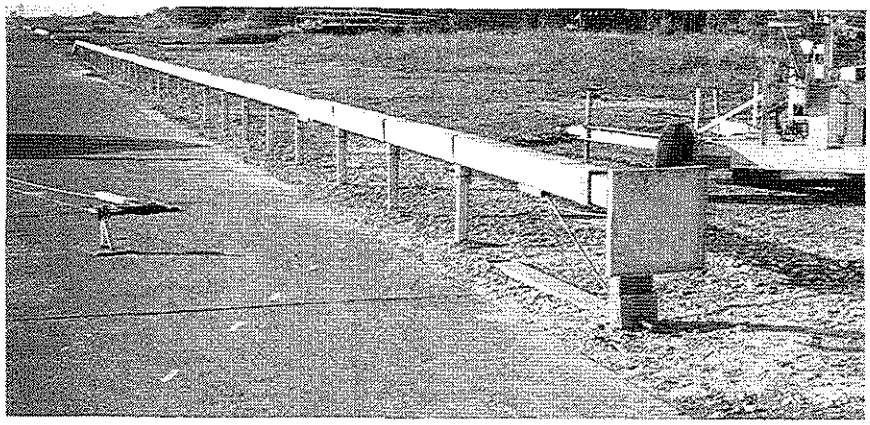
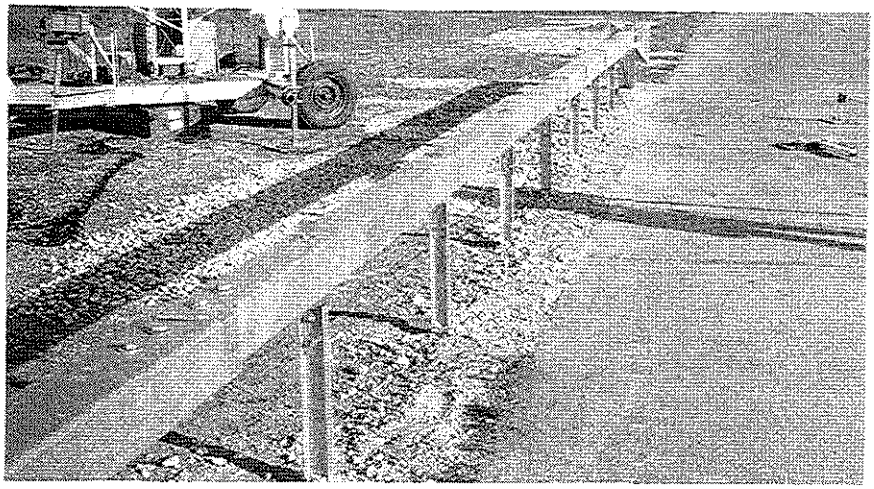


Figure 2. Schematic of test installation.





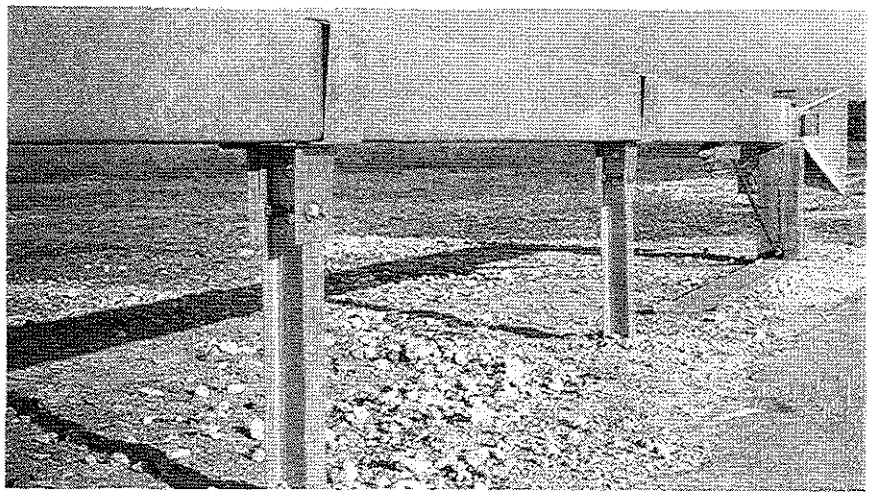
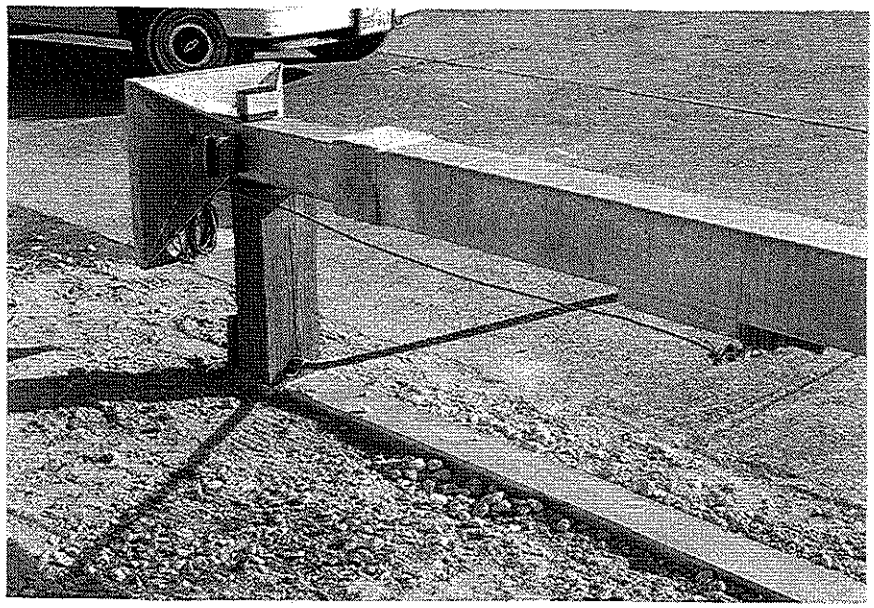


Figure 3. Wyoming box-beam test installation before test 472020-6.



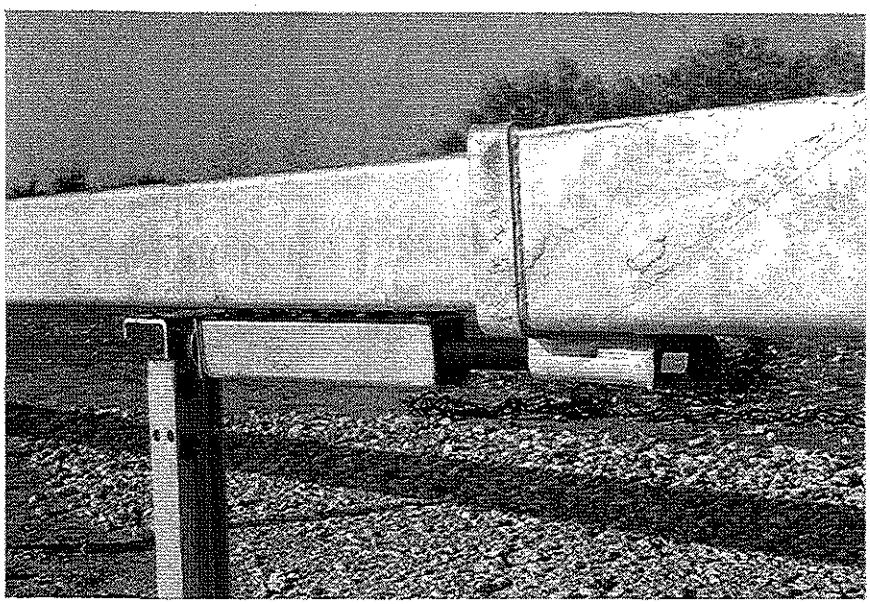


Figure 4. Wyoming box-beam end terminal before test 472020-6.

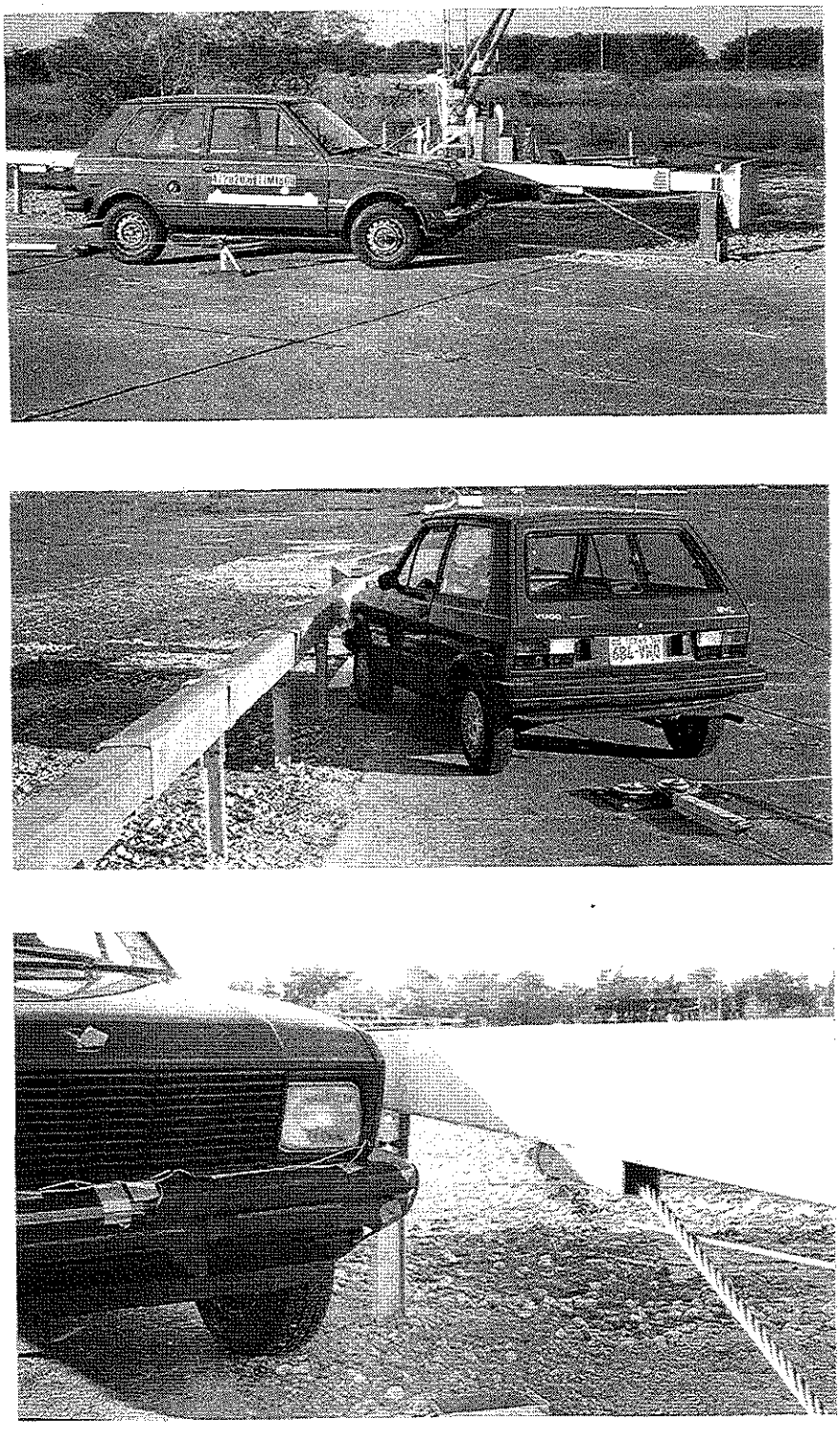


Figure 5. Vehicle/end terminal geometrics for test 472020-6.

Figure 6. Vehicle before test 472020-6.

and 14 in. (356 mm), respectively. Other dimensions and information on the vehicle are given in Figure 7. The vehicle was directed into the test installation using the cable reverse tow and guidance system and was free wheeling and unrestrained just prior to impact

The vehicle impacted the terminal at a speed and angle of 61.6 mi/h (99.1 km/h) and 19.2 degrees. Upon impact, the rail element began to deflect laterally. The left front tire moved under the rail and impacted the end of the cable anchor mounted on the bottom of the rail at approximately 0.044 second, resulting in the tire airing out. Simultaneous to the left front tire impacting the end of the cable anchor, the vehicle bumper impacted the cable and began to tension the cable. By 0.062 second, the left front tire was wedged under the rail. As the vehicle began to redirect, the cable was released from the vehicle bumper at 0.076 second and the left front wheel began to ride under the cable. The cable remained in contact with the left front wheel and acted to guide the vehicle down and into the wooden end post. The front of the vehicle contacted the wooden end post at 0.080 second and the post broke off at approximately 0.123 second. The vehicle impacted the impact head assembly shortly thereafter. The impact head assembly was pushed out of the outer tube and thrown forward by the impacting vehicle. The forward motion of the impact head assembly was then arrested by the restraining cable and came to rest on the ground. Also, as the wooden end post broke and released the tension on the cable anchor, the cable anchor bearing plate was thrown up underneath the vehicle and apparently snagged on the transmission housing of the vehicle at approximately 0.168 second. This restrained the forward movement of the vehicle on the left front and the vehicle began to yaw rapidly in a counterclockwise direction and decelerate abruptly. By 0.222 second, the bearing plate was released from the vehicle and the vehicle continued to yaw out and came to rest 62.5 ft (19.1 m) downstream from the initial point of impact and 19.7 ft (6.0 m) behind the rail installation. The vehicle was in contact with the rail installation for a total length of 7 ft (2.1 m). Sequential photographs of the test are shown in Figures 8 and 9.

The barrier sustained relatively minor damage, as shown in Figure 10. The wooden end post was broken off at ground level and the outer tube was detached from posts 2 through 4. The post angles at posts 6 through 8 were bent as well as most of the support plates for the median barrier due to tension acting on the rail element from loading of the cable by the left front wheel of the vehicle. The impact head assembly was disengaged from the outer tube during the collision sequence and came to rest behind the installation. The top of the end post foundation tube and the connection of the ground channel strut to the end post foundation tube were slightly bent. Other than

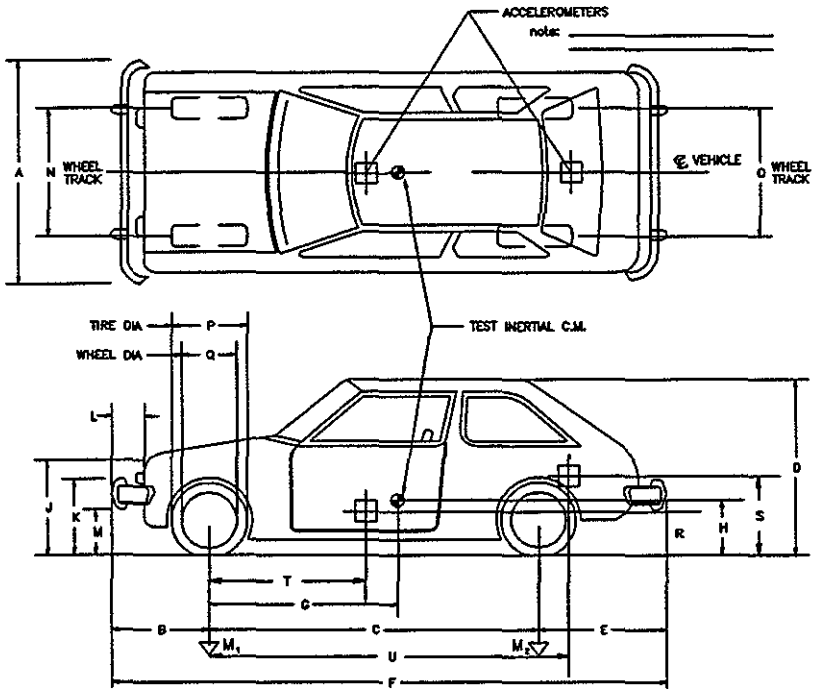
DATE: 10-26-93 TEST NO.: 472020-6 VIN NO.: VX1BB121JK422405 MAKE: Yugo

MODEL: GVL YEAR: 1988 ODOMETER: 51243 TIRE SIZE: 145SR13

TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF 256 RF 258 LR 144 RR 158

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 4 cyl gas

ENGINE CID: 1100 cc

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

_____

_____

_____

DUMMY DATA:

TYPE: _____

MASS: _____

SEAT POSITION: _____

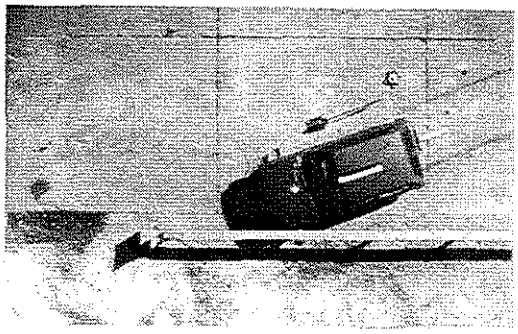
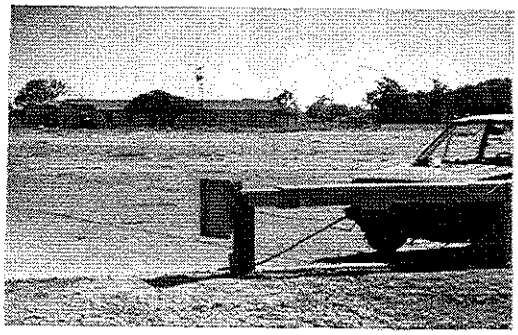
1 mm = 0.039 in
1 kg = 2.202 lb

GEOMETRY – (mm)

A	1473	E	660	J	756	N	1308	R	381
B	686	F	3480	K	490	O	1300	S	724
C	2146	G	795	L	64	P	584	T	787
D	1670	H		M	356	Q	362	U	2413

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	518	514	551
M_2	282	302	342
M_T	800	816	893

Figure 7. Vehicle properties for test 472020-6.

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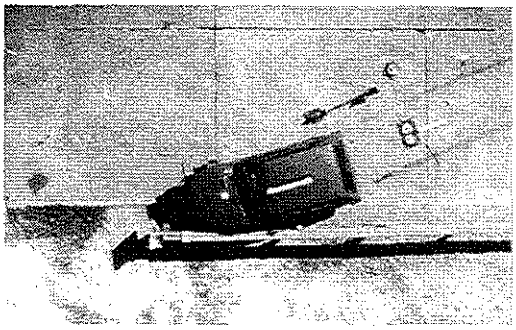
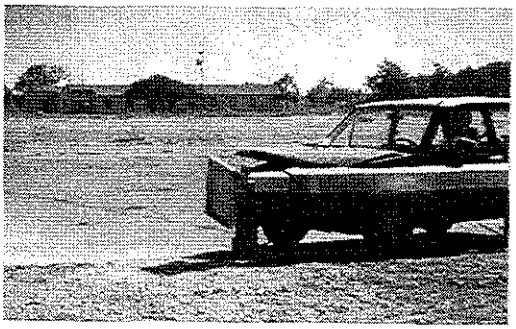

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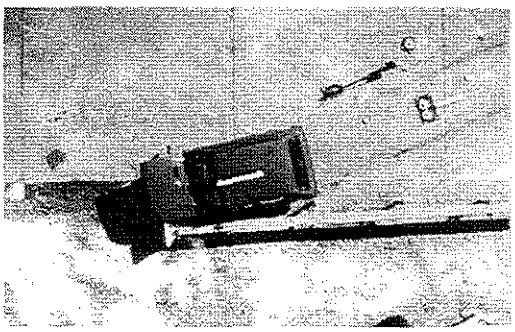
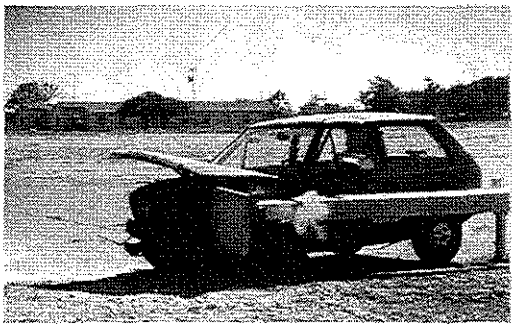
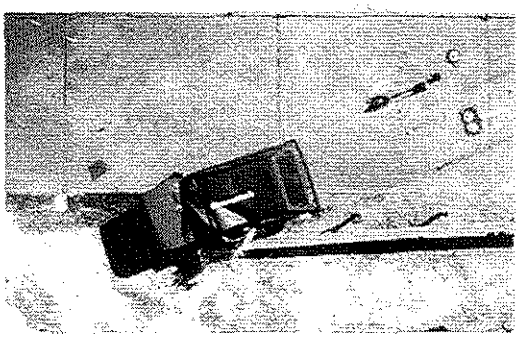
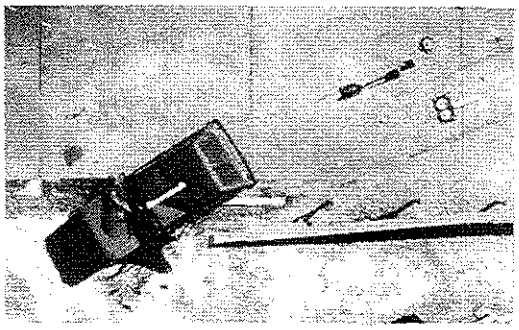
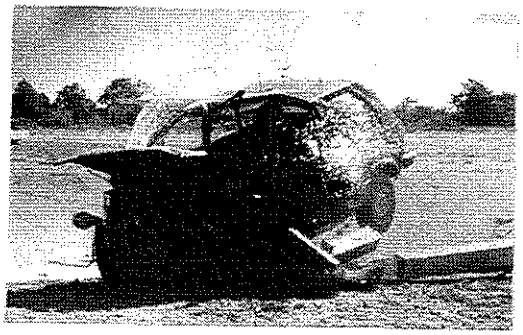



0.107 s



0.160 s

Figure 8. Sequential photographs for test 472020-6.
(overhead and frontal views)

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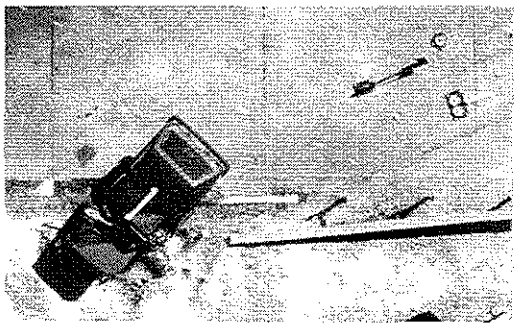

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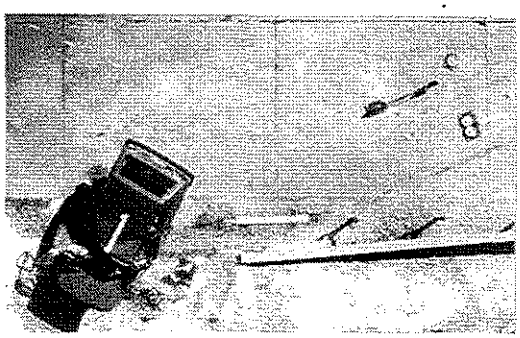
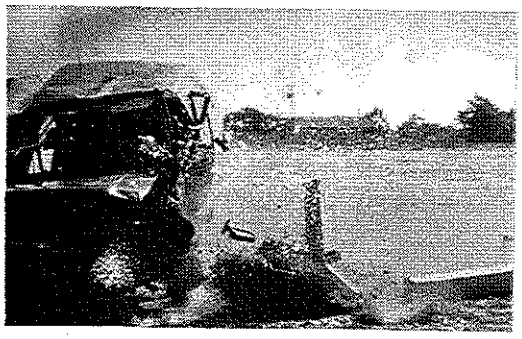
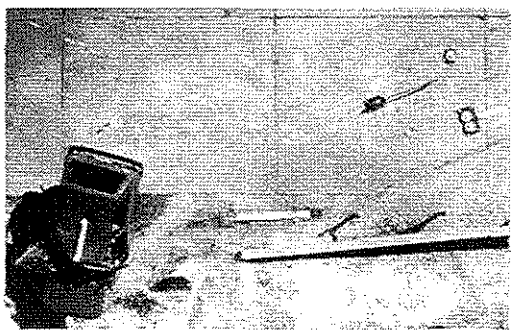
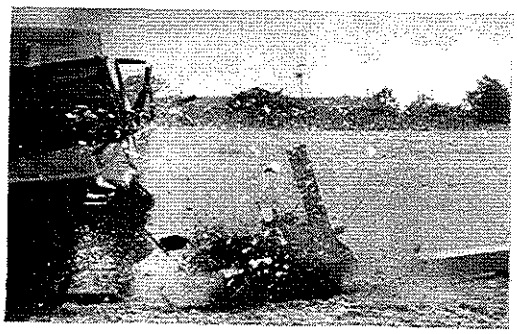



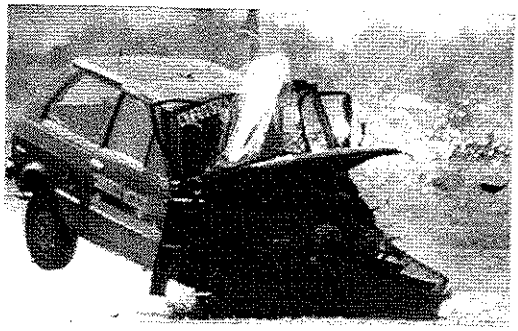
0.321 s

0.374 s

Figure 8. Sequential photographs for test 472020-6 (continued).
(overhead and frontal views)

0.000 s

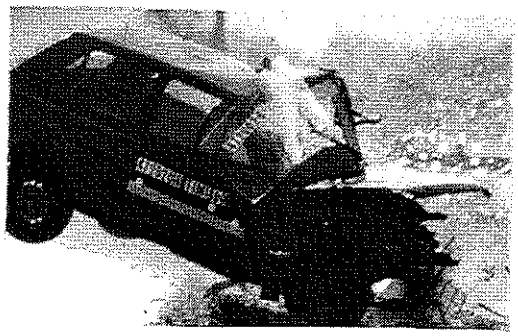


0.214 s

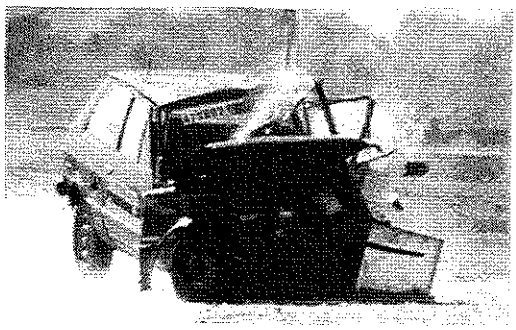
0.053 s

0.267 s

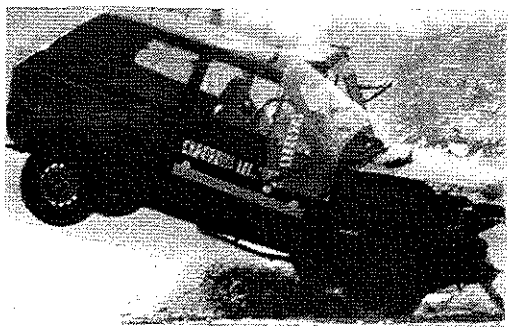
0.107 s



0.321 s



0.160 s



0.374 s

Figure 9. Sequential photographs for test 472020-6.
(behind the rail view)

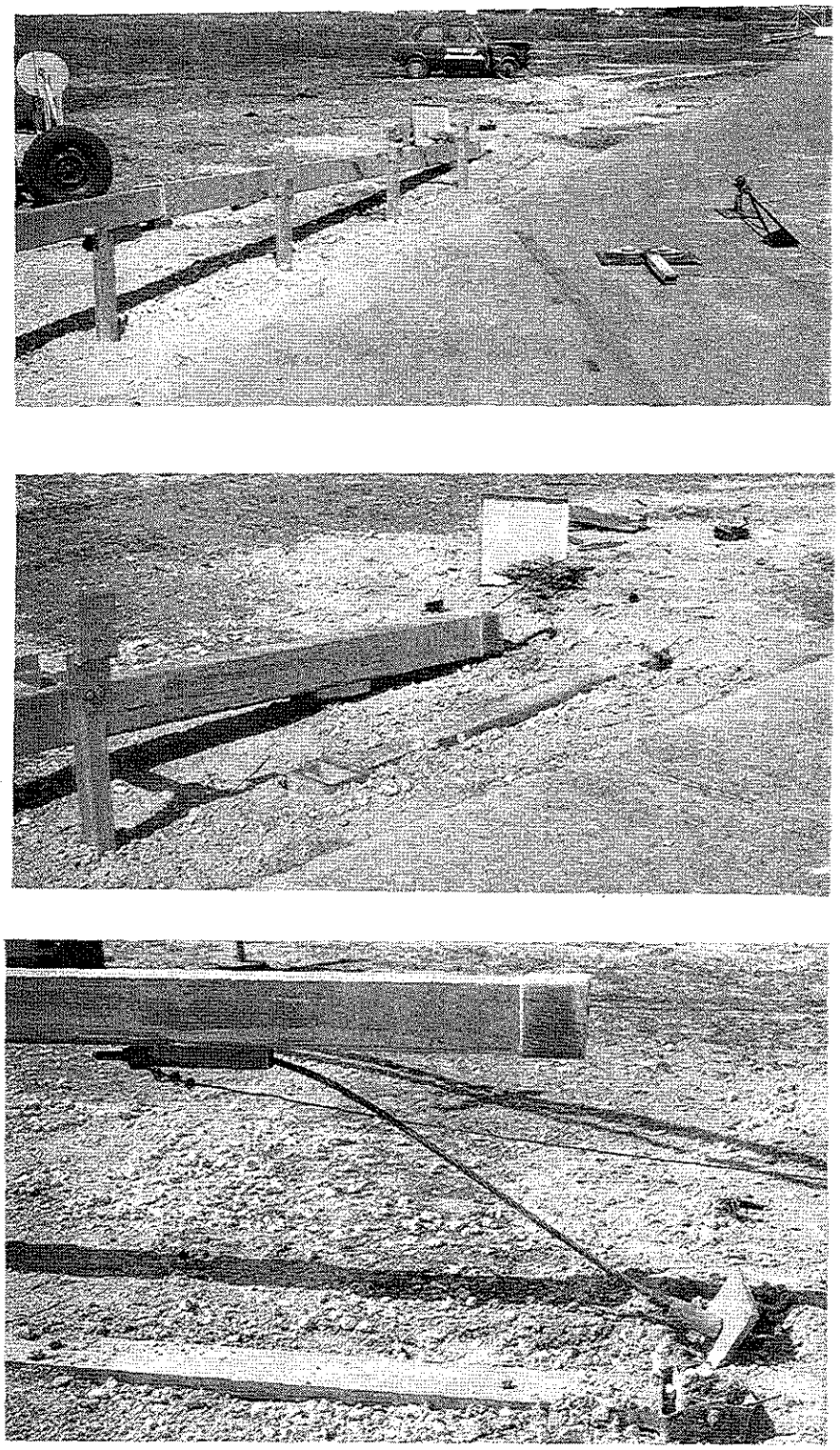


Figure 10. Wyoming box-beam end terminal after test 472020-6.

replacement of the wooden end post, most of the other damage was either cosmetic in nature or could be easily repaired..

The vehicle received severe damage, as shown in Figure 11. The damage sustained was concentrated at the left front quarter of the vehicle. Maximum crush was 24 in. (610 mm) at the left front corner the vehicle. In addition, the right front corner of the vehicle was shifted 16 in. (406 mm) to the left. The transmission housing was broken, probably from snagging by the cable anchor bearing plate. The floor pan of the vehicle was torn and the firewall and instrument panel/dashboard were bent. Almost all the body panels were deformed forward of the rear axle and the roof was buckled. There was intrusion into the occupant compartment at the fire wall and floor pan areas of the vehicle interior.

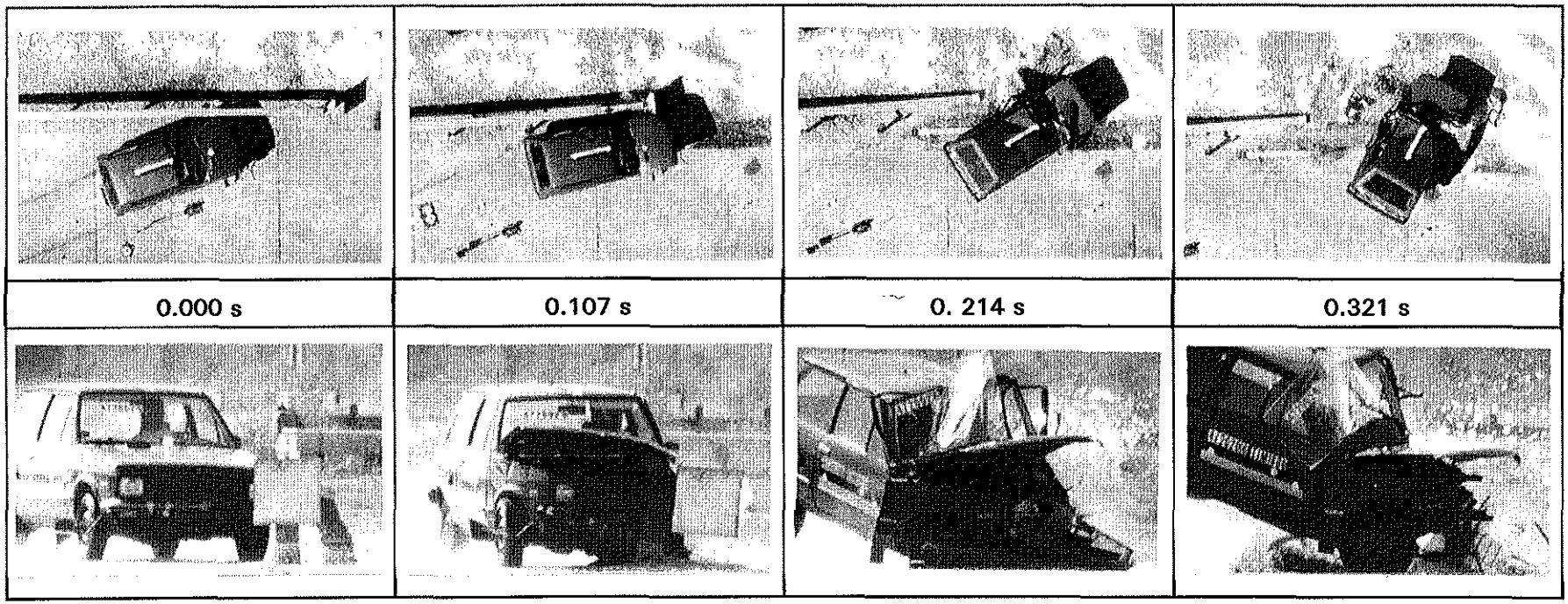
Data from the accelerometer located at the center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 43.0 ft/s (13.1 m/s), the highest 0.010-second average ridedown acceleration was -7.7 g and the maximum 0.050-second average acceleration was -19.6 g. In the lateral direction, occupant impact velocity was -3.1 ft/s (-0.9 m/s), the highest 0.010-second average ridedown acceleration was -3.5 g and the maximum 0.050-second average lateral acceleration was -5.2 g. These data and other pertinent information from the test are summarized in Figure 12. Vehicular angular displacements are displayed in Figure 13. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 14 through 16.

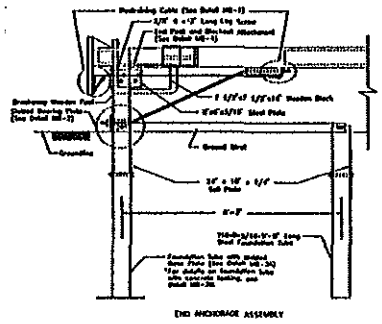
In summary, the barrier is judged to have performed unsatisfactorily in this reverse direction test. Analysis of the test results indicated two independent events that led to the unsatisfactory impact performance of the end terminal design in the reverse direction impact:

1. The left front wheel of the vehicle was wedged underneath the cable anchor, resulting in very high deceleration rate on the vehicle prior to breaking of the wooden end post and release of the cable anchor.

2. As the wooden end post broke and released the tension on the cable anchor, the cable anchor bearing plate was thrown up underneath the vehicle and snagged on the transmission housing of the vehicle. This restrained the forward movement of the vehicle on the left front, resulting in the vehicle yawing rapidly in a counterclockwise direction and decelerating abruptly.

Figure 11. Vehicle after test 472020-6.





Test No.	472020-6	Impact Speed	61.6 mi/h (99.1 km/h)
Date	10/26/93	Impact Angle	19.2 degrees
		Speed at Parallel	N/A
Test Installation	Wyoming Box-Beam End Terminal	Exit Speed	N/A
		Exit Trajectory	N/A
Installation Length	217 ft (66.1 m)	Vehicle Accelerations (Max 50-ms Avg)	
Test Vehicle	1988 Yugo	Longitudinal	-19.6 g
Vehicle Weight		Lateral	-5.2 g
Test Inertia	1800 lb (816 kg)	Occ. Impact Velocity	
Gross Static	1969 lb (893 kg)	Longitudinal	43.0 ft/s (13.1 m/s)
Vehicle Damage Classification		Lateral	-3.1 ft/s (-0.9 m/s)
TAD	11LFQ7	Occ. Ridedown Acc.	
CDC	11FLEW5	Longitudinal	-7.7 g
Maximum Vehicle Crush	24.0 in (610 mm)	Lateral	-3.5 g

Figure 12. Summary of results for test 472020-6.

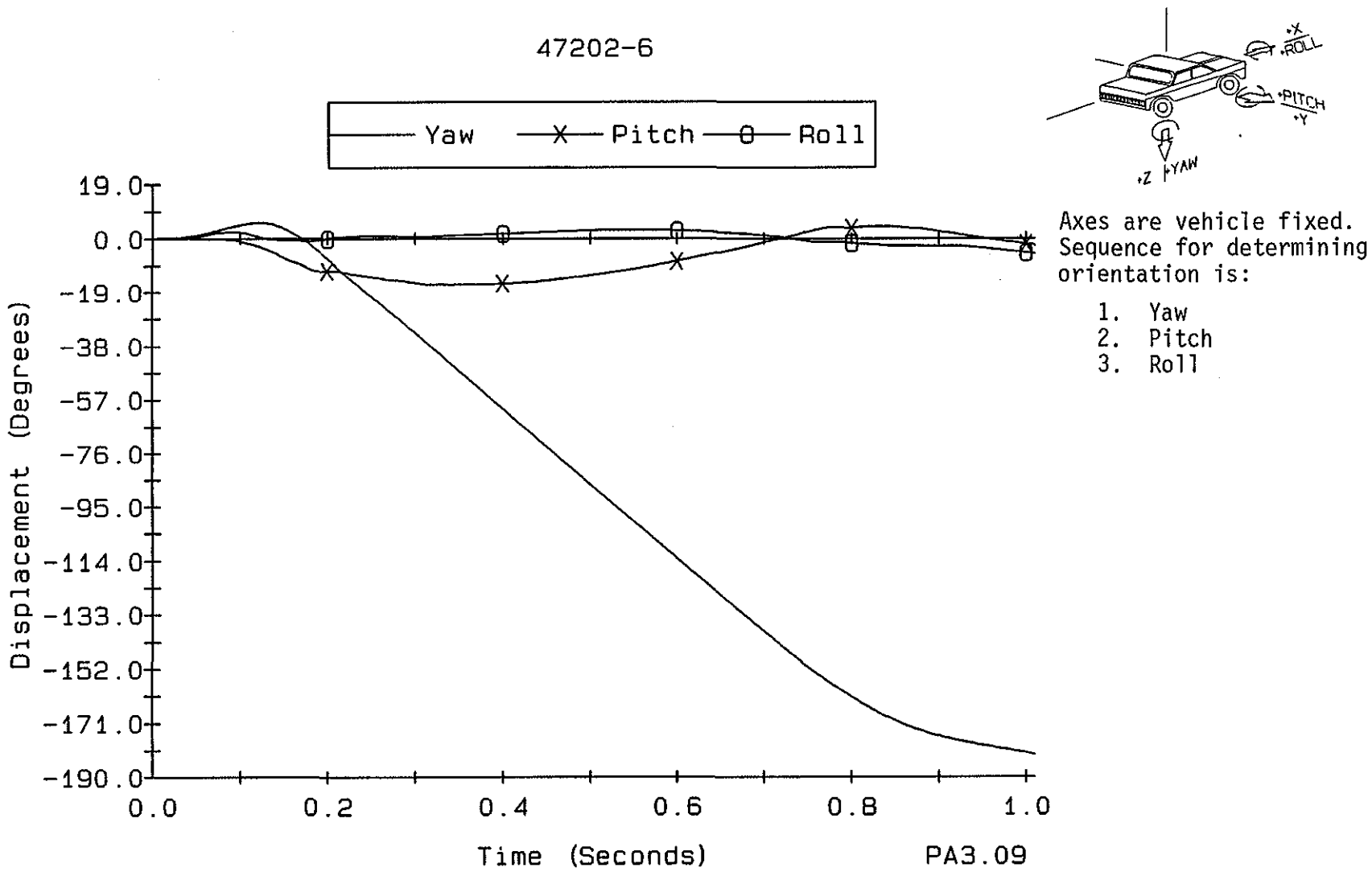


Figure 13. Vehicle angular displacements for test 472020-6.

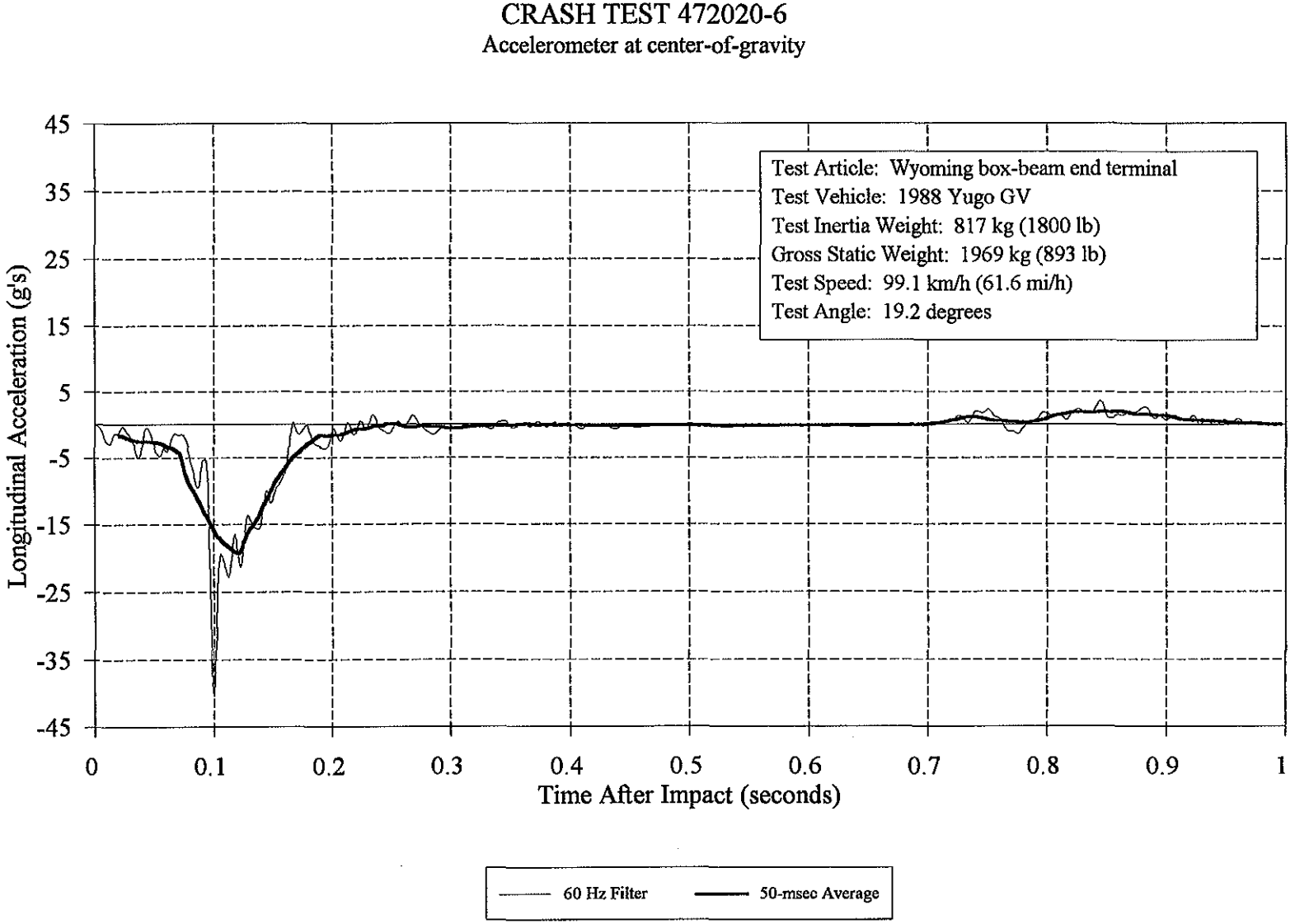


Figure 14. Vehicle longitudinal accelerometer trace for test 472020-6.

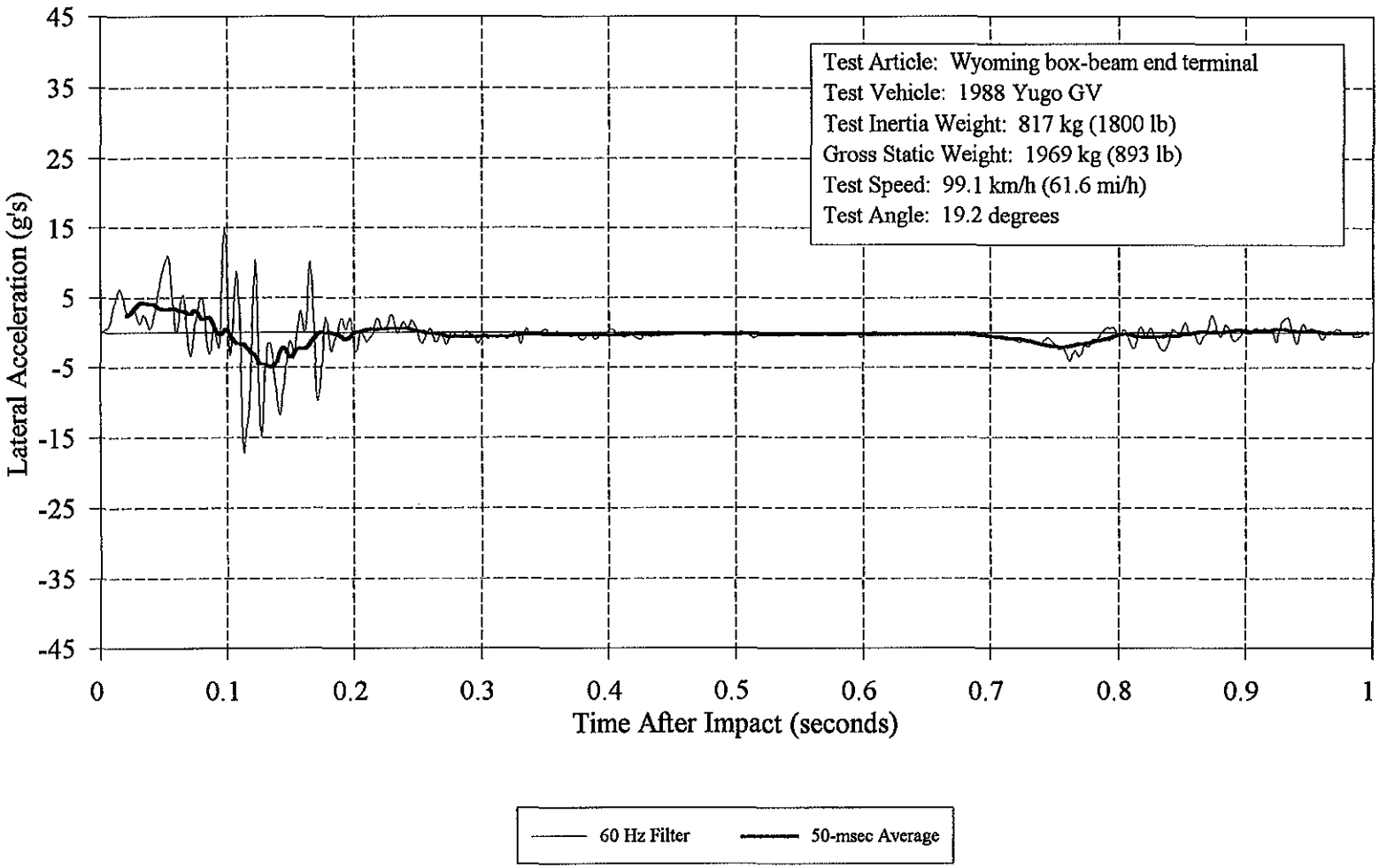


Figure 15. Vehicle lateral accelerometer trace for test 472020-6.

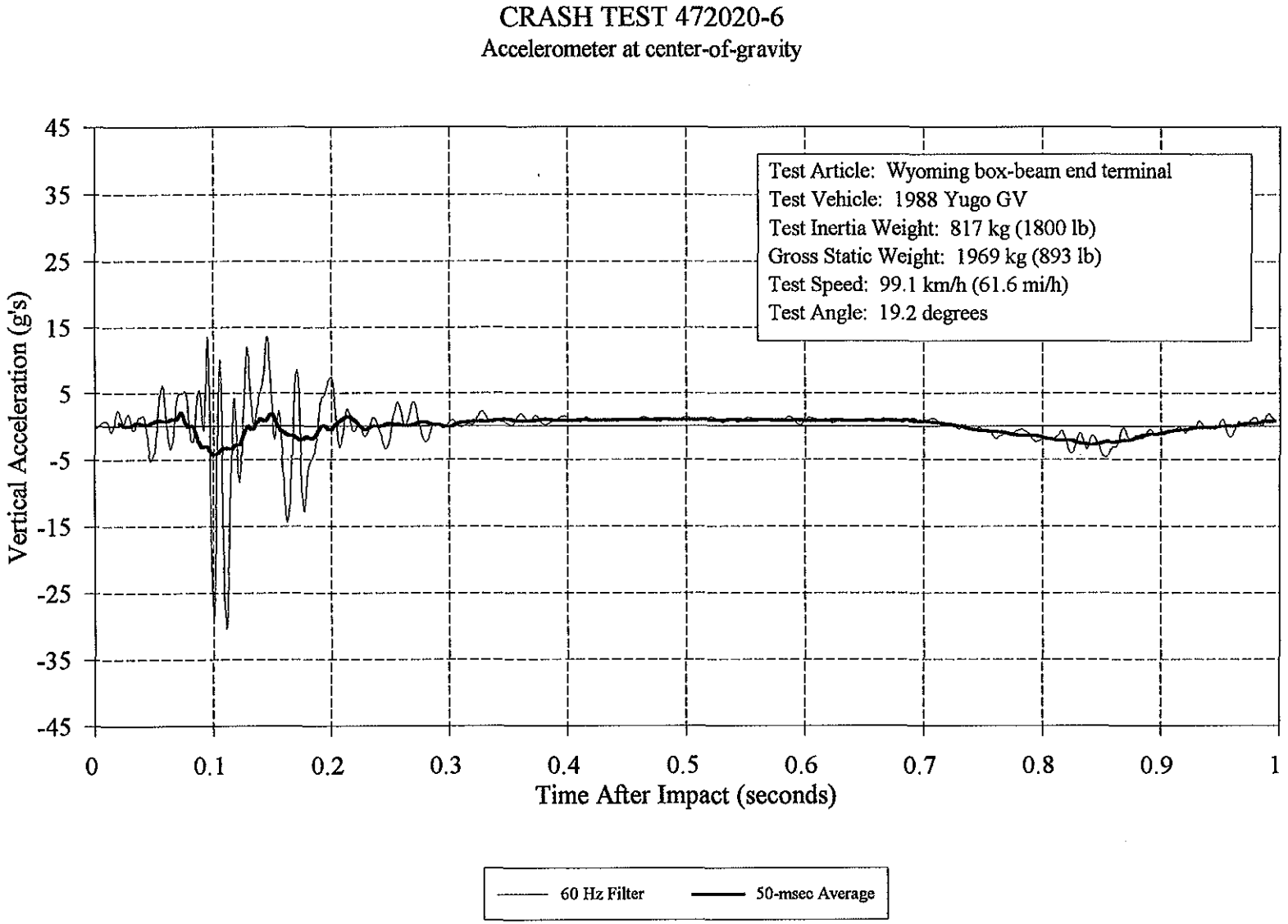


Figure 16. Vehicle vertical accelerometer trace for test 472020-6.

Design modifications to eliminate this behavior were developed and are described as follows:

1. A 7-1/2 in. x 7-1/2 in. x 14-in. (191 mm x 191 mm x 356 mm) wooden blockout was attached to the side of the wooden end post underneath the impact head to facilitate breaking of the end post prior to the left front wheel of the vehicle being wedged underneath the anchor cable. The wooden blockout is bolted to the side of the wooden end post with two steel brackets.

2. The cable anchor bearing plate was redesigned with a slotted configuration so that the bearing plate would separate from the cable anchor upon breaking of the wooden end post. This eliminates the potential of the bearing plate catching or snagging on some part of the undercarriage of the vehicle.

3. The plate washer used for attaching the downstream end of the cable anchor to the box beam was redesigned to minimize the potential of the tire airing out upon impact with the plate washer, which could effectively lower the left front of the vehicle, rendering the left front tire of the vehicle more susceptible to wedging under the cable.

Two pendulum tests were conducted to make sure that the attachment of the wooden blockout to the end post and the slotted cable anchor bearing plate would perform as intended. The pendulum tests were conducted with successful results. These design modifications were then incorporated into the test installation and the small car reverse direction impact was repeated.

4.2 Repeat of Small Car Reverse Direction Test (Test No. 472020-7)

The test installation was repaired and reconstructed (Figure 17) and the small car reverse direction test was repeated. A 1988 Yugo GV (shown in Figures 18 and 19) was used with the test. Test inertia mass or empty weight of the vehicle was 1,801 lb (817 kg) and the gross static mass or test weight of the vehicle was 1,969 lb (893 kg), including a restrained 50th percentile male anthropomorphic dummy placed in the driver's position. The heights to the upper and lower edges of the vehicle bumper were 18.9 in. (480 mm) and 13.2 in. (335 mm), respectively. Other dimensions and information on the vehicle are given in Figure 20. The vehicle was directed into the test installation using a cable reverse tow and guidance system and was free wheeling and unrestrained just prior to impact.

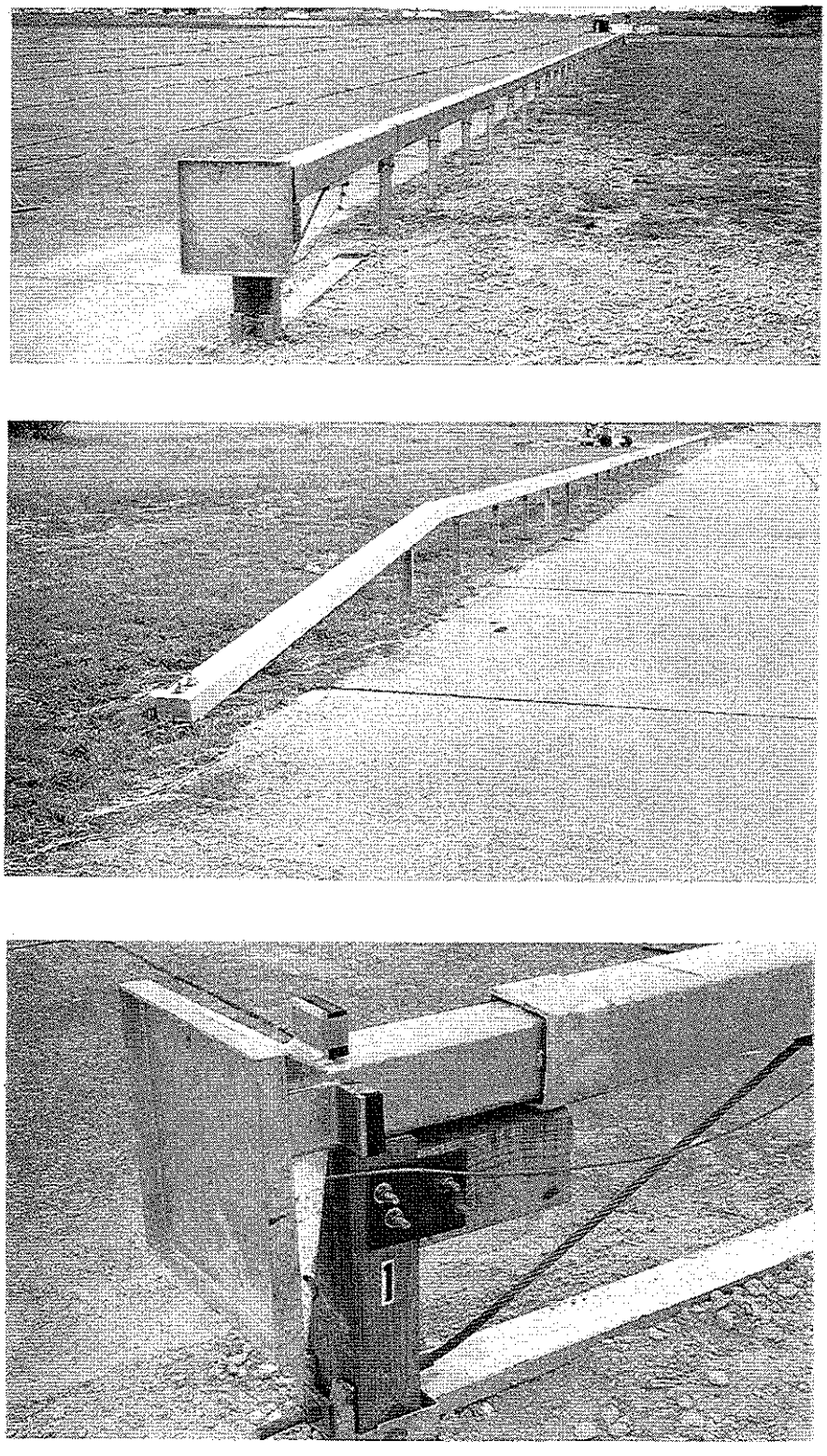
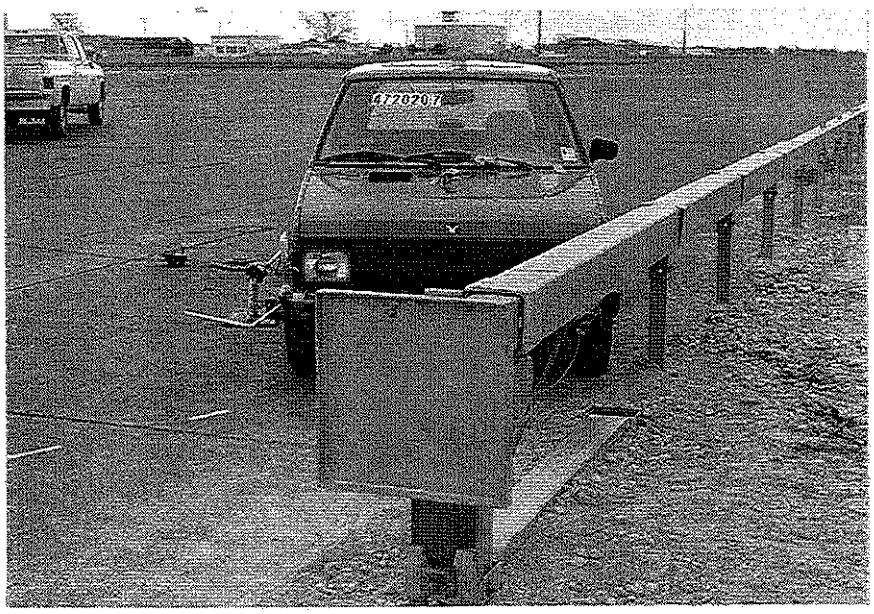


Figure 17. Wyoming box-beam rail installation before test 472020-7.



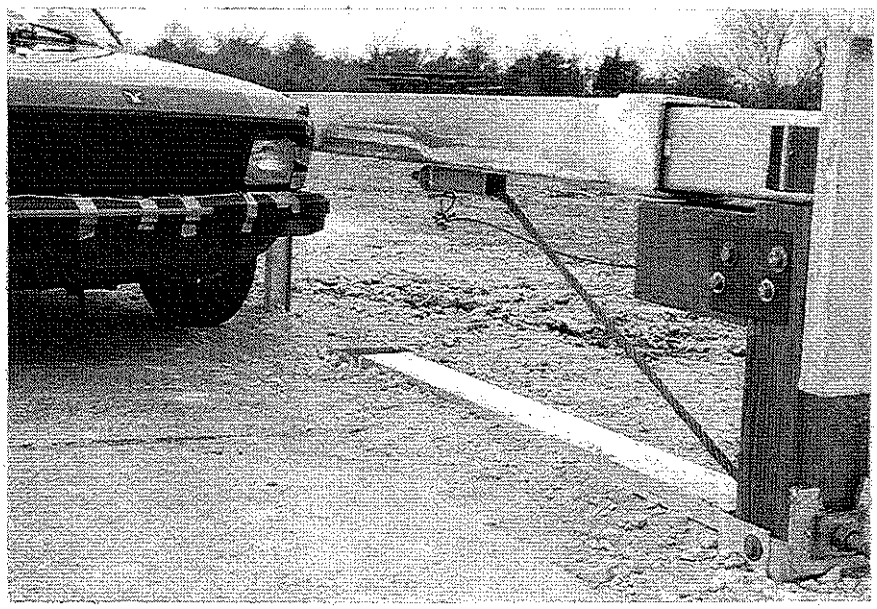


Figure 18. Vehicle/rail geometrics for test 472020-7.

Figure 19. Vehicle before test 472020-7.

DATE: 12-03-93 TEST NO.: 472020-7 VIN NO.: VX1BA1219JK429677 MAKE: Yugo

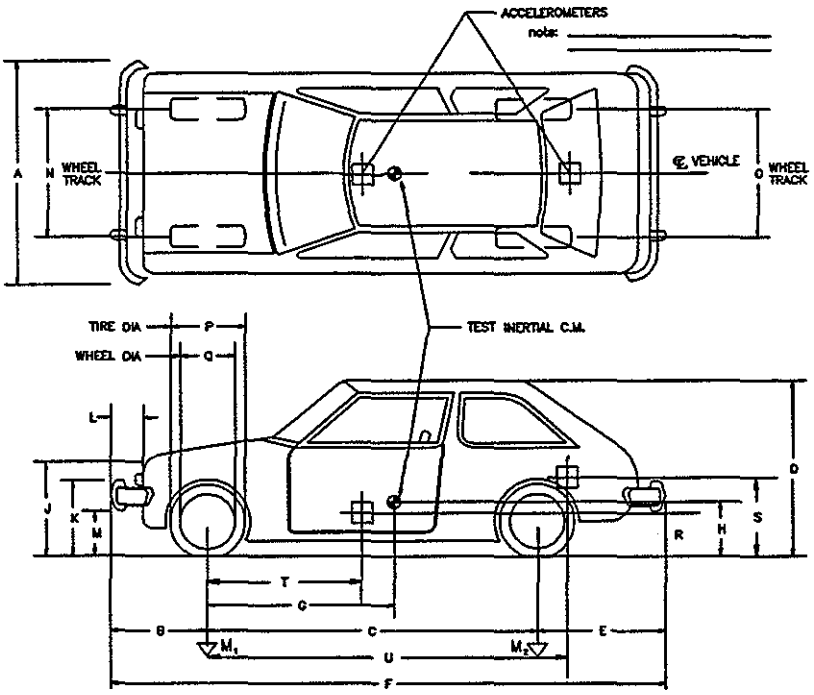
MODEL: GV YEAR: 1988 ODOMETER: 56418 TIRE SIZE: 145 SR 13

TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF 257 RF 255 LR 147 RR 158

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Chip in windshield (marked)



ENGINE TYPE: 4 cylinder

ENGINE CID: 1100 cc

TRANSMISSION TYPE:

__ AUTO

X MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: _____

MASS: _____

SEAT POSITION: _____

1 mm = 0.039 in
1 kg = 2.202 lb

GEOMETRY – (mm)

A	1470	E	610	J	710	N	1310	R	390
B	670	F	3420	K	480	O	1265	S	700
C	2140	G	799	L	60	P	570	T	800
D	1430	H		M	335	Q	365	U	2380

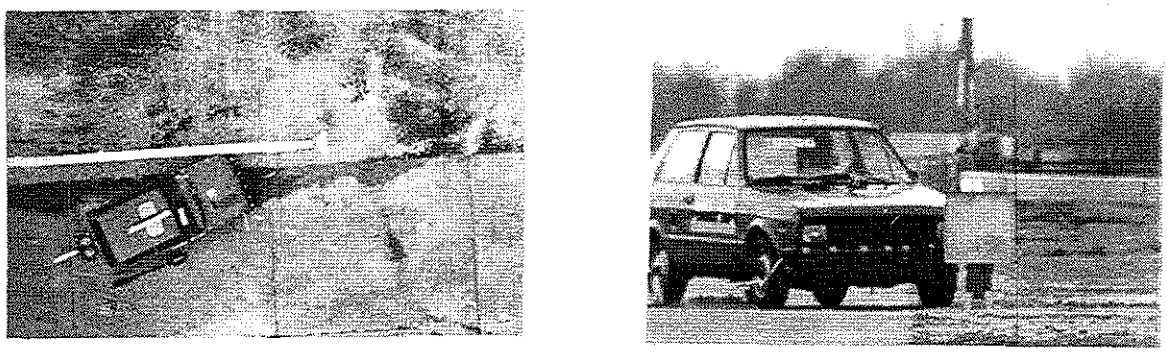
MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	515	512	548
M_2	270	305	345
M_T	785	817	893

Figure 20. Vehicle properties for test 472020-7.

The vehicle impacted the end terminal in the reverse direction approximately 8 ft-1 in. (2.5 m) downstream of the nose, which is the mid-point between the nose and the beginning of length-of-need, at a speed and angle of 60.3 mi/h (97.0 km/h) and 21.8 degrees. Upon impact, the bumper began to ride under the cable anchor and the rail began to deflect laterally. At approximately 0.049 second, the left front tire began to ride under the cable anchor. The wooden end post broke at approximately 0.071 second and the vehicle impacted the impact head assembly shortly thereafter. By 0.091 second, the cable anchor bearing plate was separated from the broken post and rotating clear of the vehicle. At 0.104 second, the impact head assembly was disengaged from the outer tube and the vehicle lost contact with the installation. The restraining cable for the impact head assembly was severed and the impact head assembly was thrown forward. Redirection to the vehicle was minimal during the impact sequence. The end terminal gated as intended, allowing the vehicle to pass and exit the installation, traveling at a speed of 49.2 mi/h (79.2 km/h) and at approximately a 14-degree angle relative to the barrier installation (i.e., 7.8 degrees of redirection). The vehicle came to rest 133 ft (40.5 m) downstream from the point of impact and 66 ft (20.1 m) behind the installation. Sequential photographs of the test are shown in Figures 21 and 22.

The barrier sustained relatively minor damage, as shown in Figure 23. The wooden end post was broken off at ground level and the outer tube was detached from posts 2 through 4. The restraining cable for the impact head assembly was severed at the attachment to the gusset plate during the impact, allowing the impact head assembly to be thrown forward after disengaging from the outer tube. Examination of the severed restraining cable showed that the cable was partially cut by the sharp edges of the hole at the gusset plate during the previous test and thus failed to restrain the impact head assembly. This problem can be minimized by using sleeves for the restraining cable at the attachment points and thus sleeves were incorporated into the design. Again, other than replacement of the wooden end post, most of the other damage was either cosmetic in nature or could be easily repaired. The vehicle was in contact with the rail for a distance of 8.2 ft (2.5 m).

The vehicle received moderate damage, as shown in Figure 24. The damage sustained was concentrated at the left front quarter of the vehicle. Maximum crush was 9.8 in. (250 mm) at the left front corner the vehicle. In addition, the left front corner of the vehicle was shifted 1.8 in. (45 mm) to the right. The left front tire, fender, and door also sustained damage and the McPhearson strut was bent. However, there was no intrusion into the occupant compartment.



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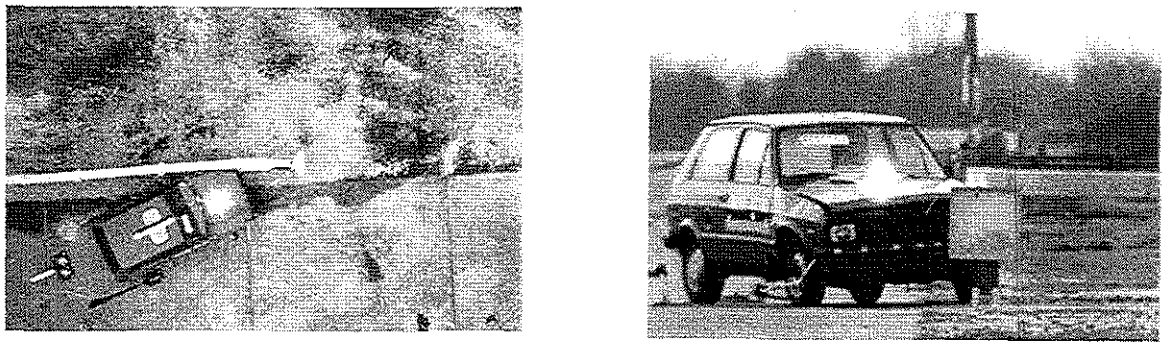

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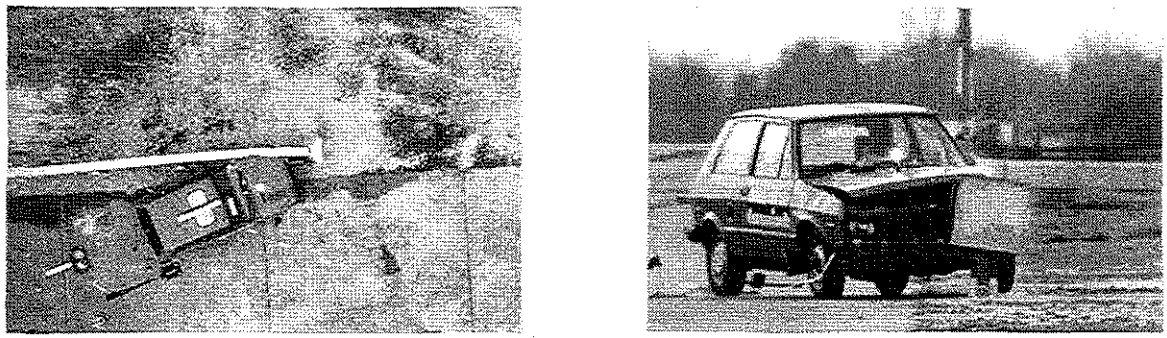

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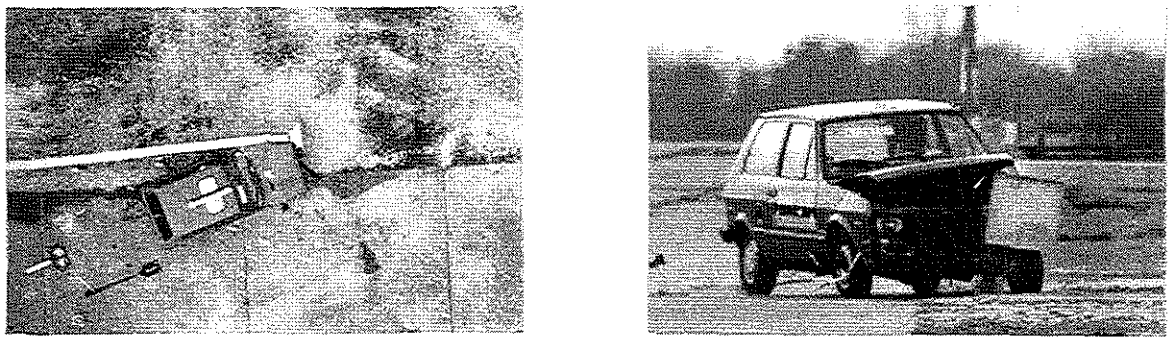
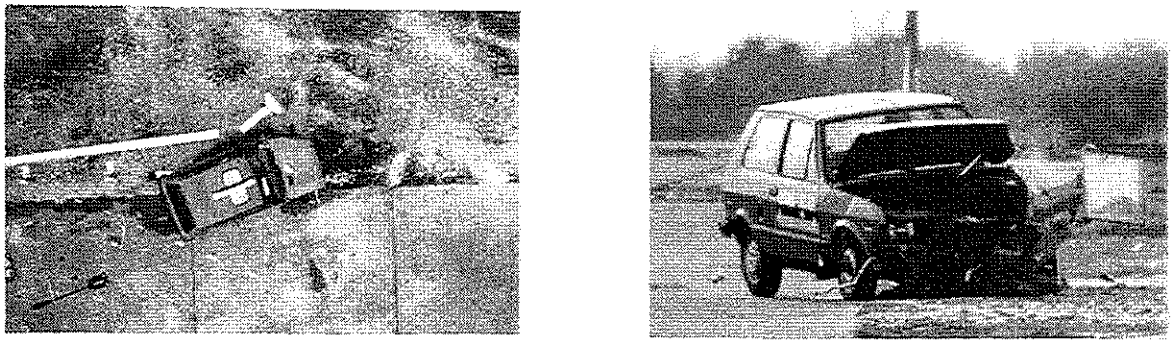


0.074 s

Figure 21. Sequential photographs for test 472020-7.
(overhead and frontal views)

0.098 s

0.123 s



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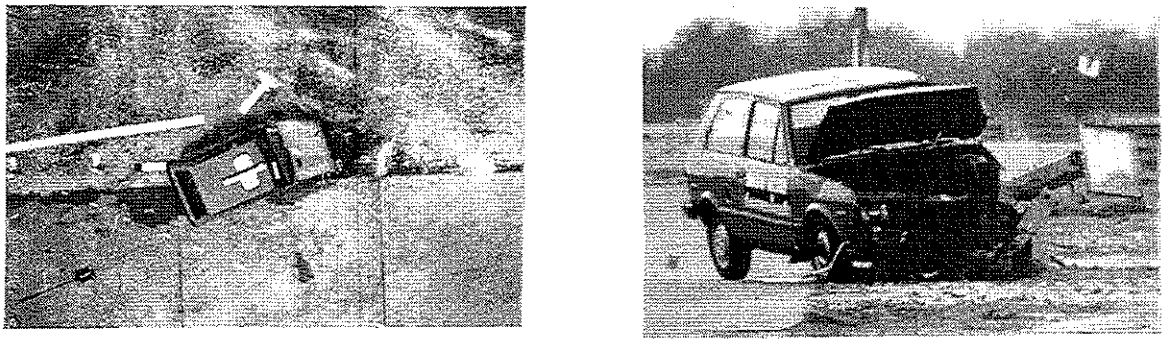
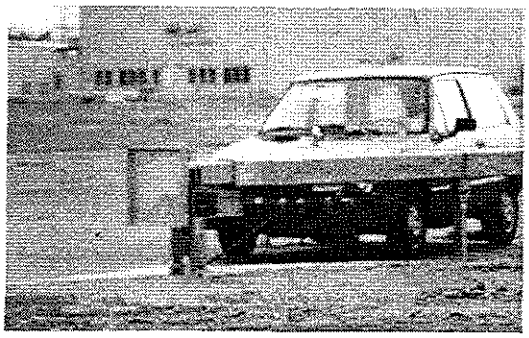


0.172 s

Figure 21. Sequential photographs for test 472020-7 (continued).
(overhead and frontal views)



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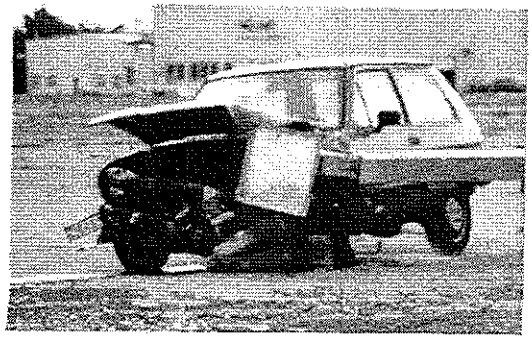
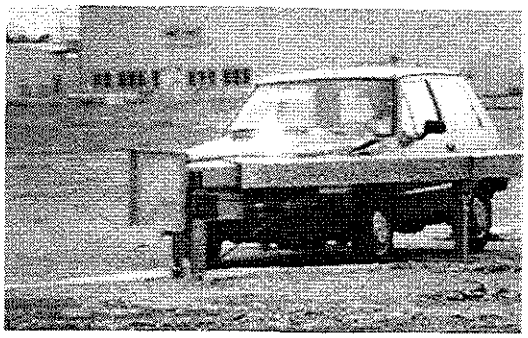
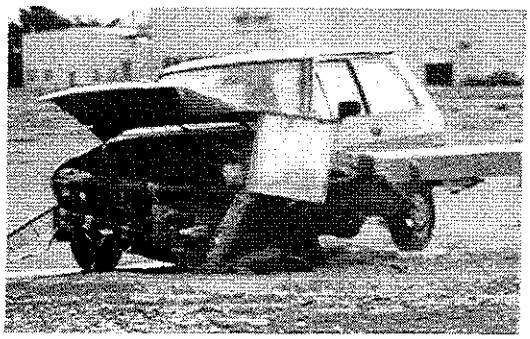


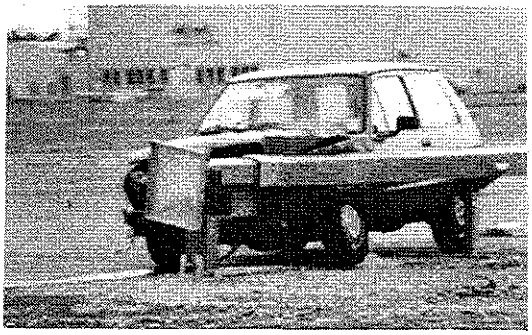
0.098 s



0.025 s



0.123 s



0.049 s

0.148 s

0.074 s

0.172 s

Figure 22. Sequential photographs for test 472020-7.
(behind the rail view)

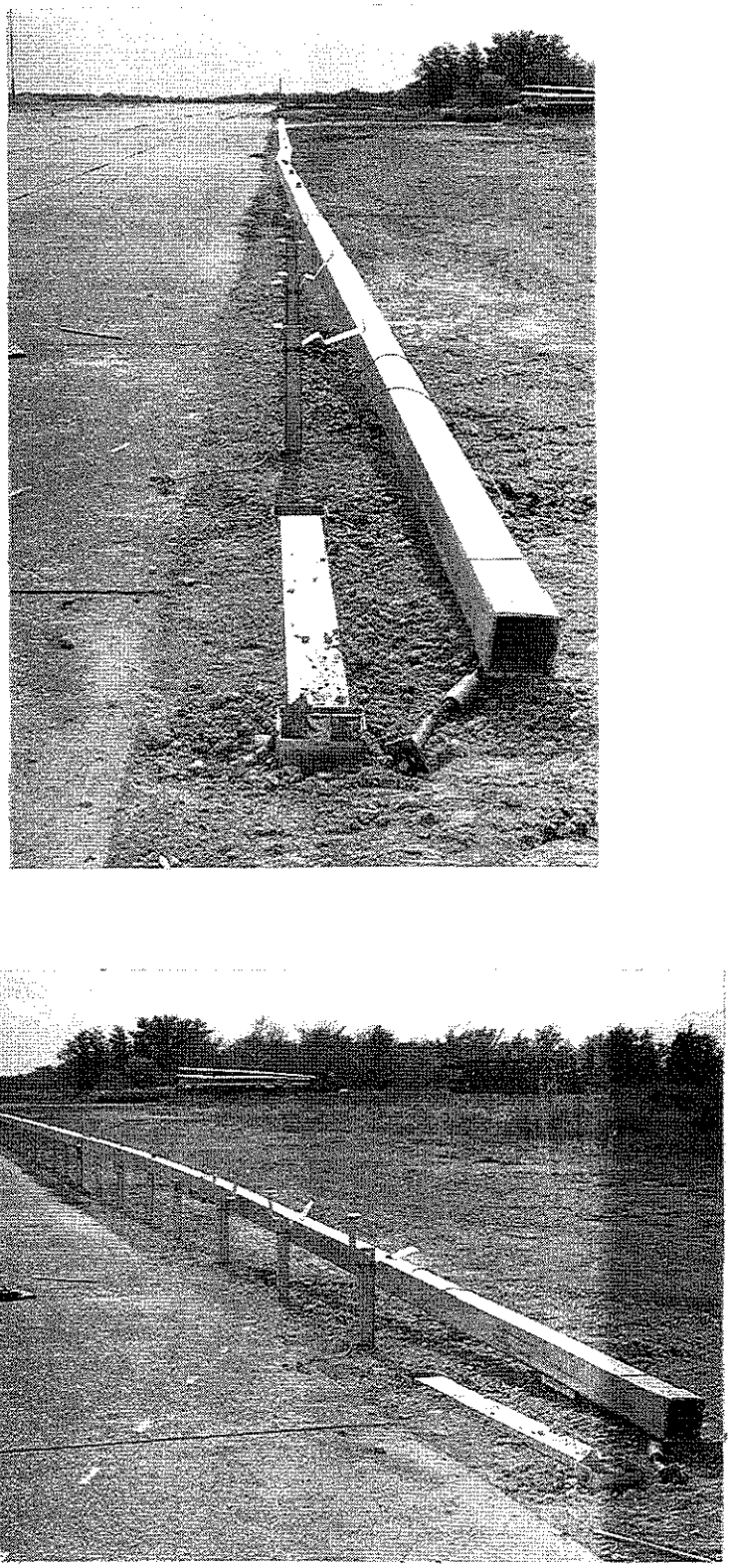
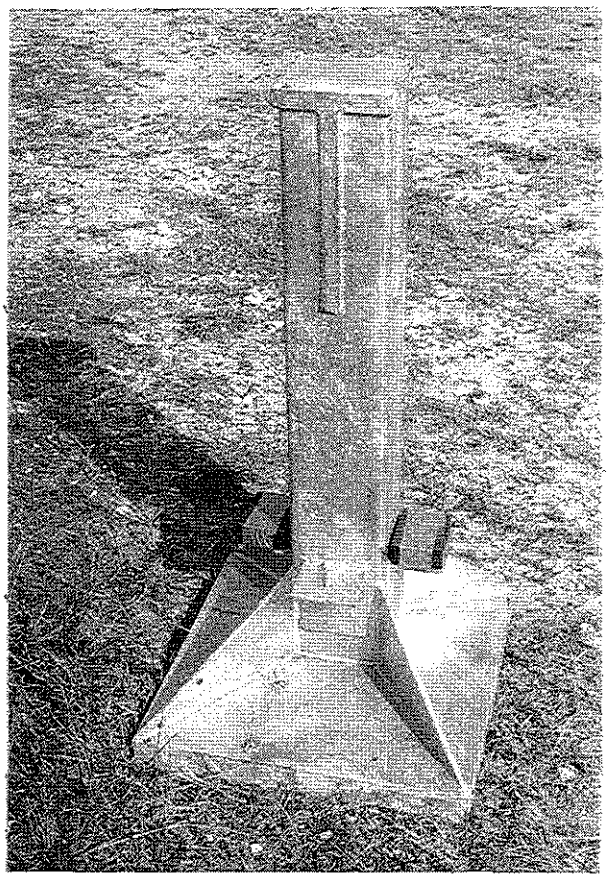


Figure 23. Wyoming box-beam rail installation after test 472020-7.



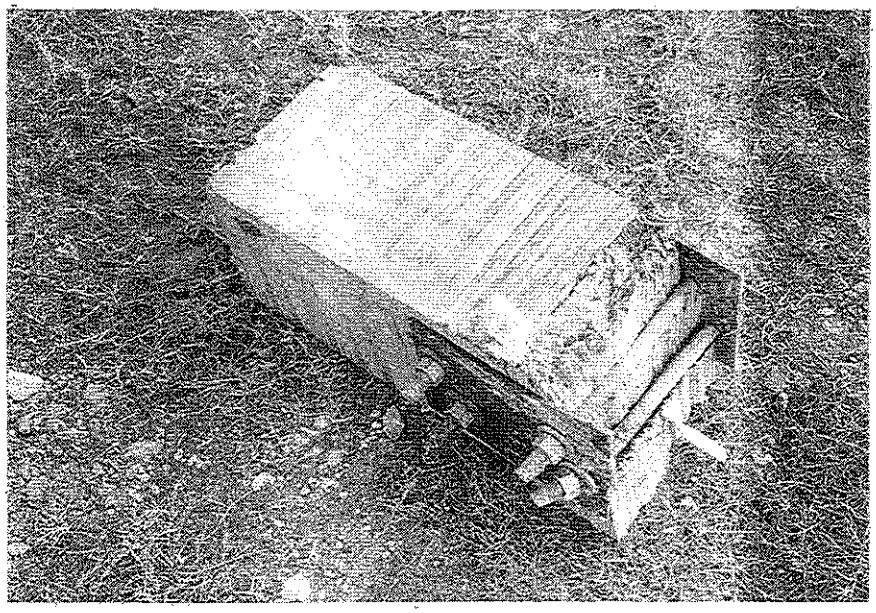


Figure 23. Wyoming box-beam rail installation after test 472020-7 (continued).

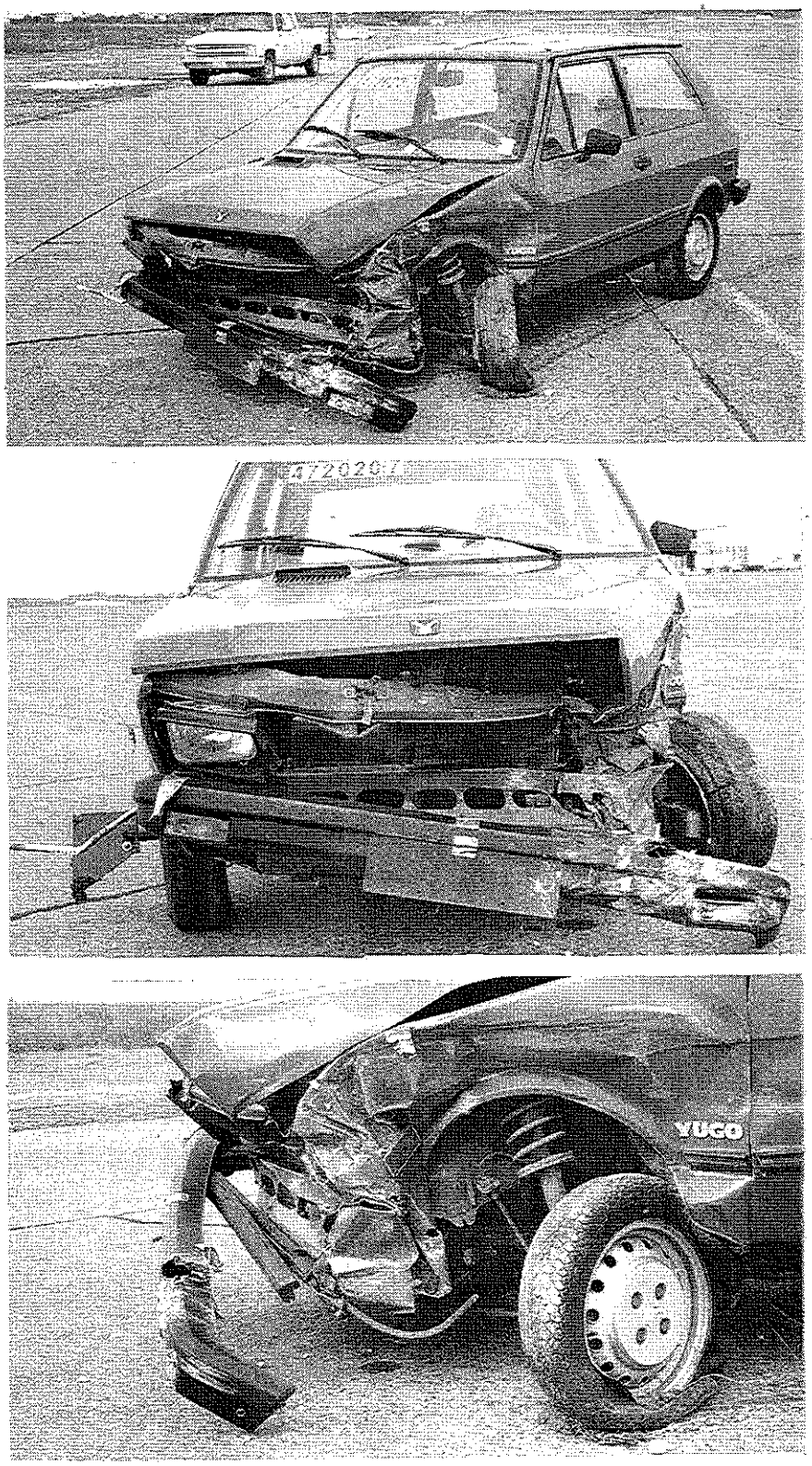


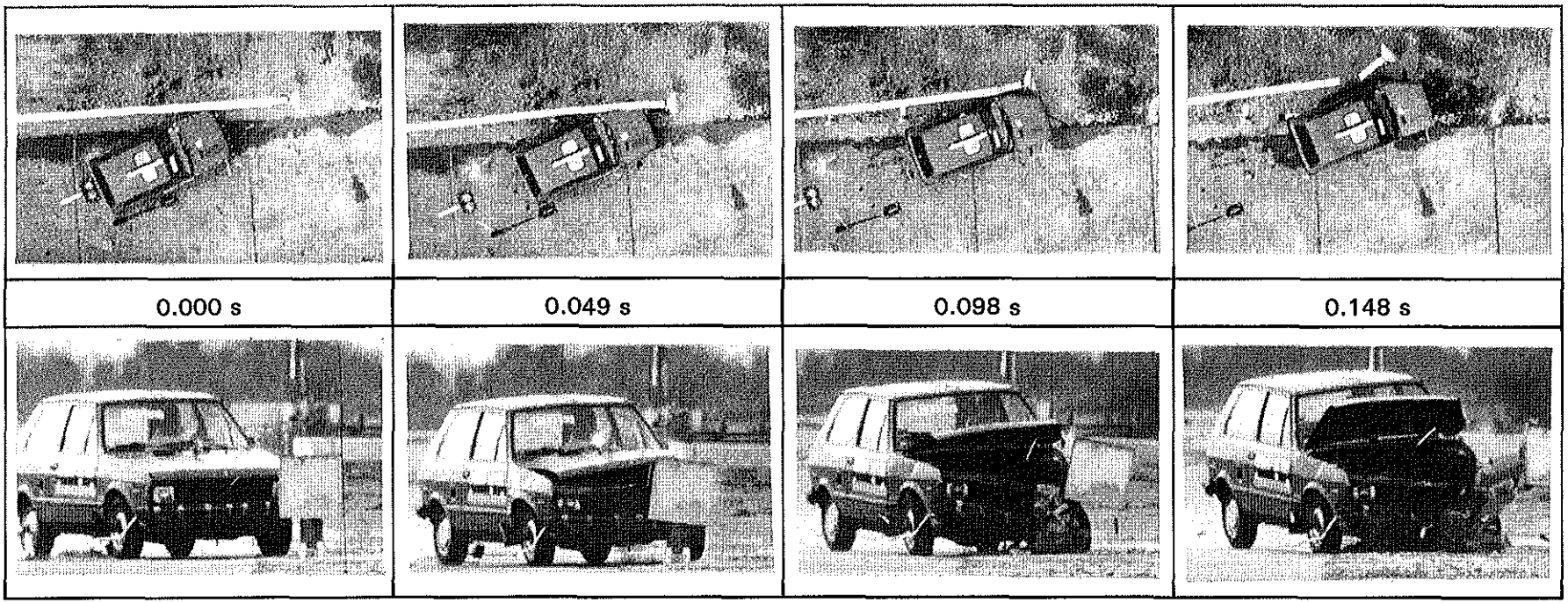
Figure 24. Vehicle after test 472020-7.

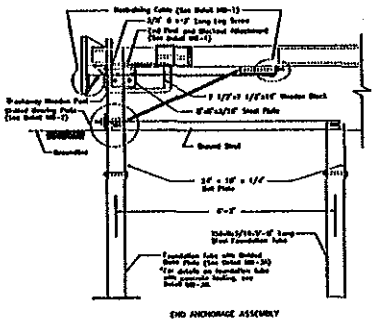
Data from the accelerometer located at the center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 20.4 ft/s (6.2 m/s), the highest 0.010-second average ridedown acceleration was -1.5 g and the maximum 0.050-second average acceleration was -8.1 g. In the lateral direction, occupant impact velocity was -5.7 ft/s (-1.7 m/s), the highest 0.010-second average ridedown acceleration was -1.8 g and the maximum 0.050-second average lateral acceleration was -5.0 g. These data and other pertinent information from the test are summarized in Figure 25. Vehicular angular displacements are displayed in Figure 26. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 27 through 29.

In summary, the barrier is judged to have performed satisfactorily in this reverse direction test. The terminal gated and allowed the vehicle to penetrate beyond the end of the terminal in a controlled manner. The wooden end post broke off prior to any significant wedging of the tire, or any other part of the impacting vehicle, under the anchor cable. The impact head assembly was thrown forward due to severing of the restraining cable at its attachment to the gusset plate. The severing of the restraining cable was caused by a partial cut of the cable by the sharp edges of the hole at the gusset plate during the previous test. This problem can be minimized by using sleeves for the restraining cable at the attachment points. Otherwise, debris or detached elements from the end terminal were concentrated along the path of the vehicle and did not pose any hazard to adjacent traffic. Both the test installation and the impacting vehicle received only minor damage. The vehicle was stable during and after the impact sequence. The vehicle exited the test installation, traveling at a speed of 49.2 mi/h (79.2km/h) and at approximately a 14-degree angle relative to the barrier installation (i.e., 7.8 degrees of redirection). The occupant risk factors are all well within the design limits set forth in NCHRP Report 230.

4.3 First Large Car Length-of-Need Strength Test (Test No. 472020-8)

The second crash test requested by FHWA is a length-of-need strength test involving a 4,500-lb (2,041-kg) passenger car impacting the end terminal at the beginning of length-of-need, i.e., post 3 or 16 ft-2 in. (4.9 m) downstream from the nose of the terminal, at a nominal speed of 60 mi/h (96.6 km/h) and at an angle of 25 degrees. The objective of this test is to evaluate the anchorage capacity of the end terminal due to concern that the median barrier terminal design offers significantly less





Test No.	472020-7	Impact Speed	60.3 mi/h (97.0 km/h)
Date	12/03/93	Impact Angle	21.8 degrees
		Speed at Parallel	N/A
Test Installation	Wyoming Box-Beam End Terminal	Exit Speed	N/A
		Exit Trajectory	N/A
Installation Length	217 ft (66.1 m)	Vehicle Accelerations (Max 50-ms Avg)	
Test Vehicle	1988 Yugo	Longitudinal	-8.1 g
Vehicle Weight		Lateral	5.0 g
Test Inertia	1800 lb (817 kg)	Occ. Impact Velocity	
Gross Static	1969 lb (893 kg)	Longitudinal	20.4 ft/s (6.2 m/s)
Vehicle Damage Classification		Lateral	-5.7 ft/s (-1.7 m/s)
TAD	11LFQ5	Occ. Ridedown Acc.	
CDC	11FLEW4	Longitudinal	-1.5 g
Maximum Vehicle Crush	9.8 in (250 mm)	Lateral	-1.8 g

Figure 25. Summary of results for test 472020-7.

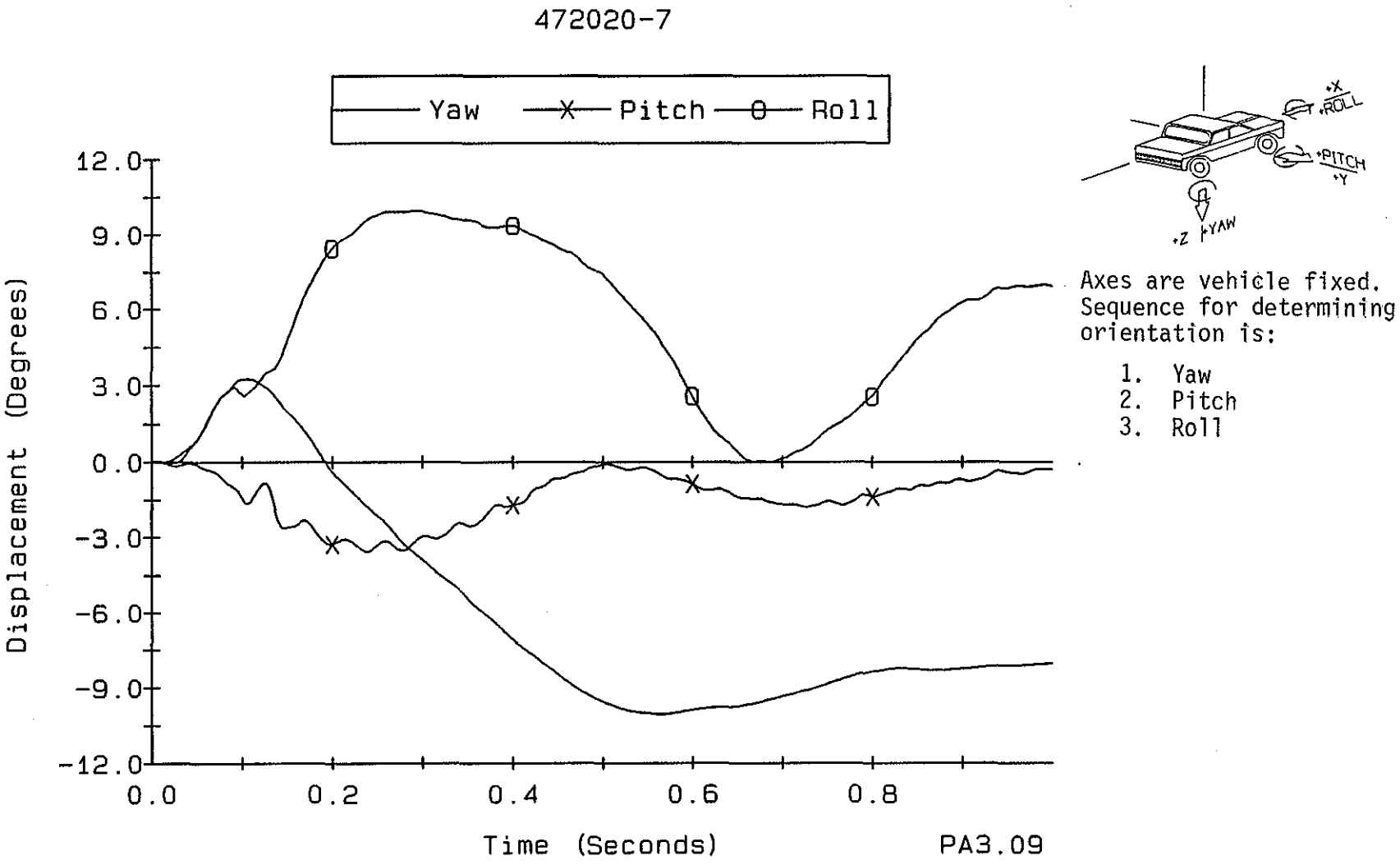


Figure 26. Vehicle angular displacements for test 472020-7.

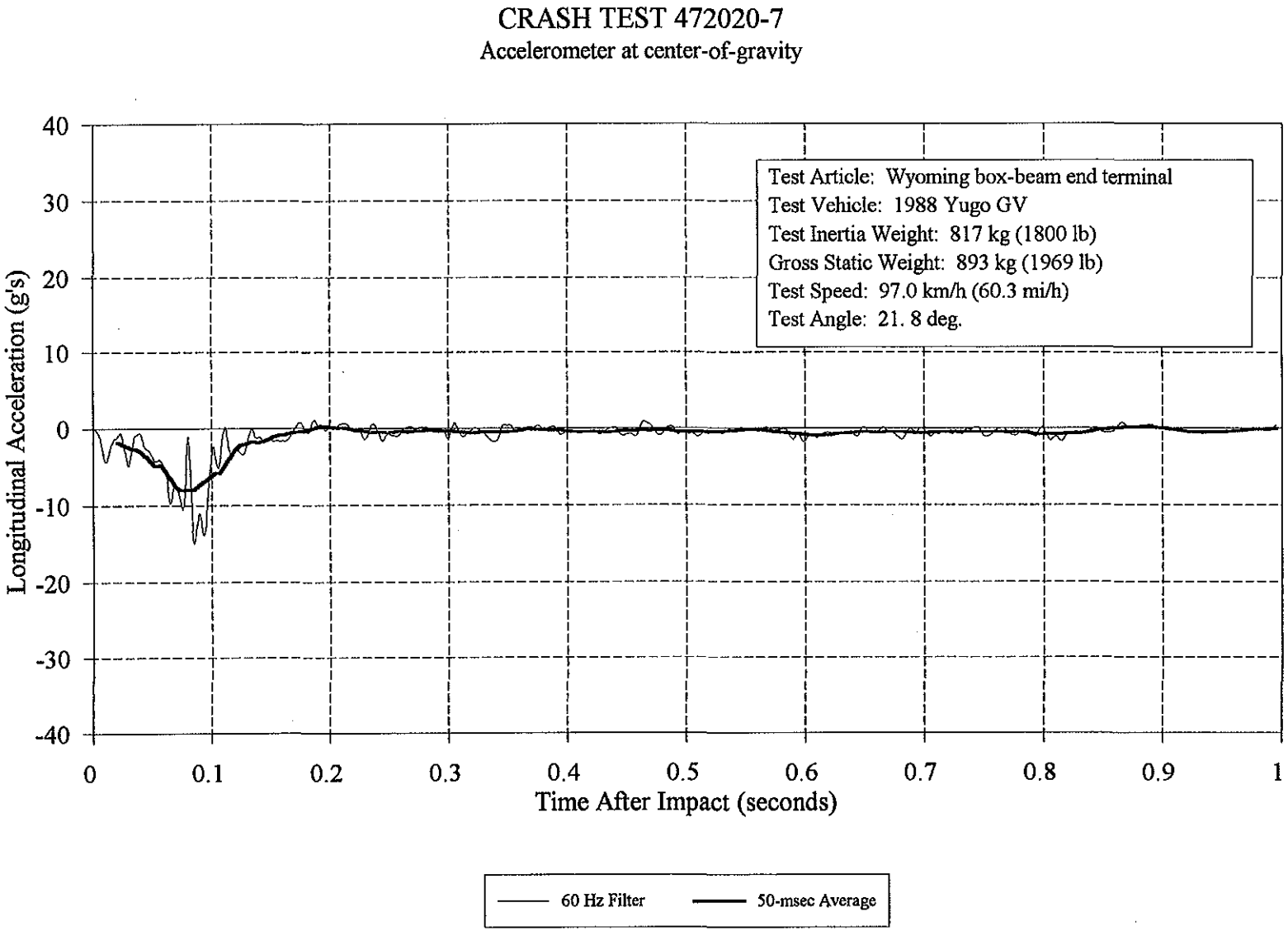


Figure 27. Vehicle longitudinal accelerometer trace for test 472020-7.

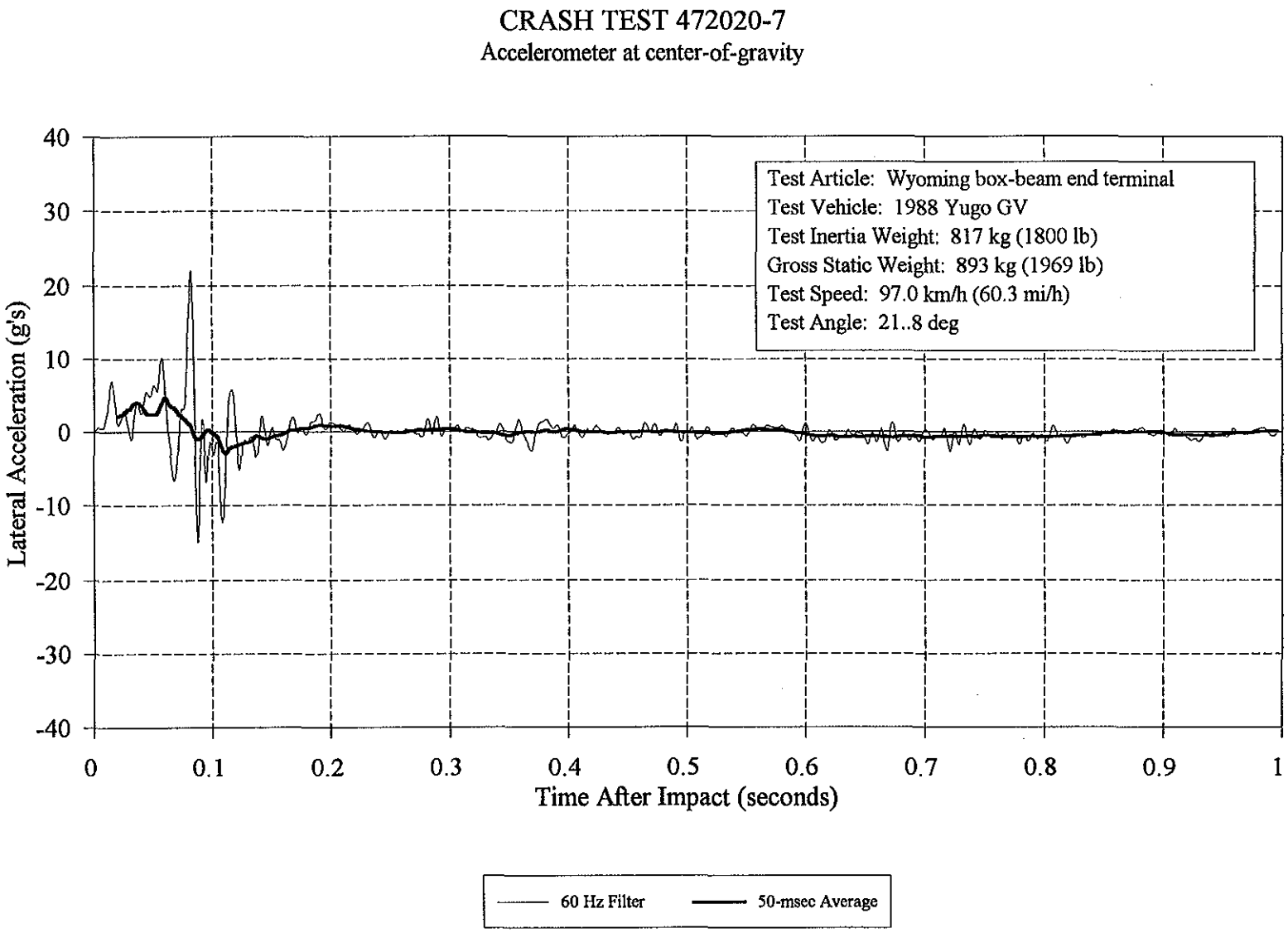


Figure 28. Vehicle lateral accelerometer trace for test 472020-7.

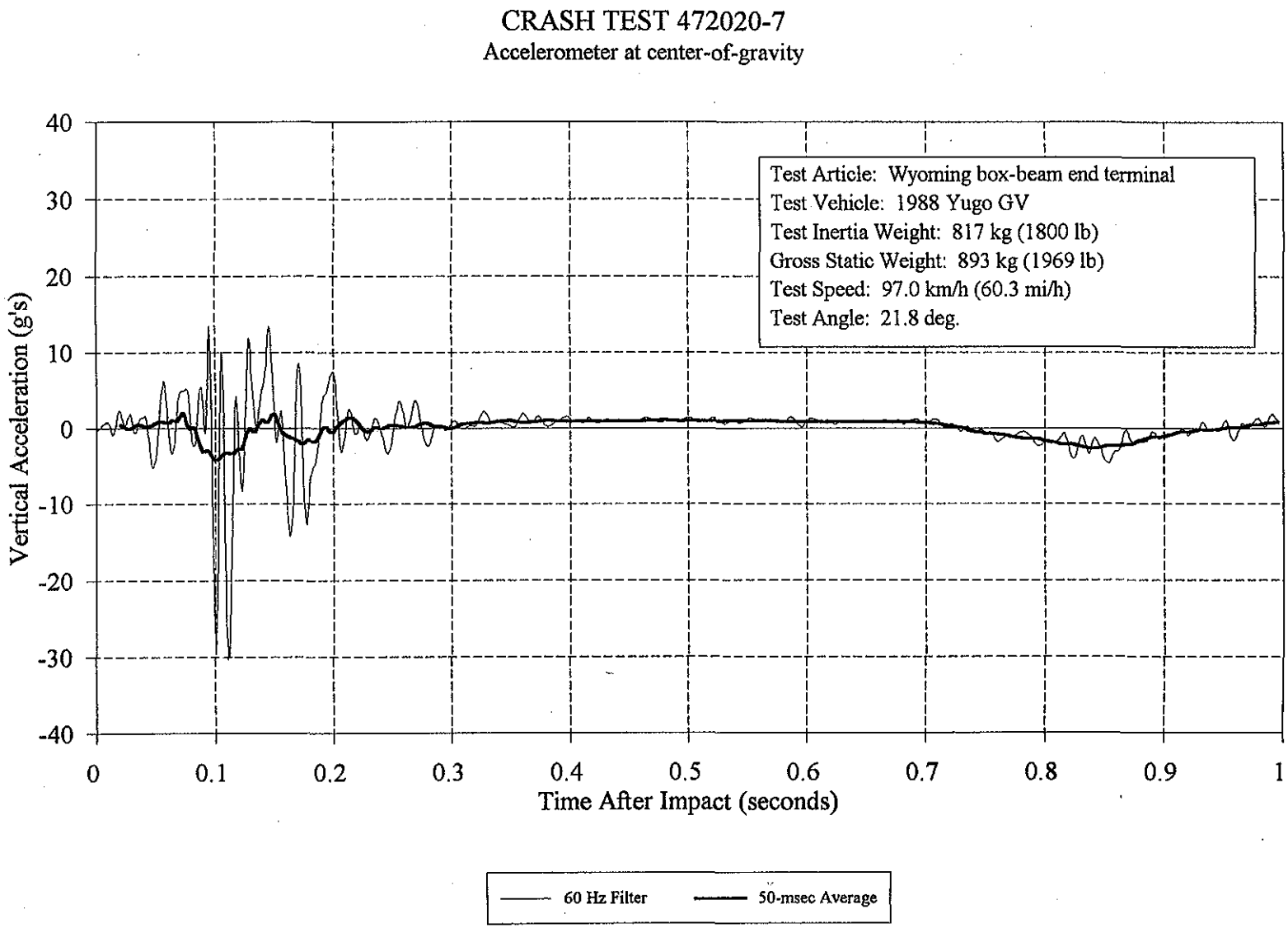


Figure 29. Vehicle vertical accelerometer trace for test 472020-7.

lateral resistance throughout its length. Photographs of the installation are shown in Figures 30 and 31.

A 1979 Cadillac Coupe DeVille (shown in Figures 31 and 32) was used with the test. Both the test inertia mass (empty weight) and the gross static mass (test weight) of the vehicle were 4,504 lb (2,043 kg). The heights to the upper and lower edges of the vehicle bumper were 20.3 in. (515.0 mm) and 12 in. (305 mm), respectively. Other dimensions and information on the vehicle are given in Figure 33. The vehicle was directed into the test installation using a cable reverse tow and guidance system and was free wheeling and unrestrained just prior to impact.

The vehicle impacted the box-beam median barrier end terminal at post 3 (beginning of length-of-need) traveling at a speed of 60.2 mi/h (96.9 km/h) and at an angle of 25.1 degrees. Upon impact, post 3 was pushed aside by the corner of the vehicle bumper, which then underrode the rail element and began to deflect the rail element laterally away from the posts. At approximately 0.049 second, the wooden end post (post 1) began to deflect rearward. At 0.058 second, the vehicle struck post 4 and the rail element was released from the shelf angle at post 4 at 0.073 second. As the vehicle was being contained and redirected by the barrier, the rail element continued to deflect laterally and was separated from the posts ahead of the vehicle trajectory. The times at which the rail element separated from the various posts are summarized in the following table:

Rail Separated from Post Number	Time (seconds)
6	0.117
7	0.124
8	0.149
9	0.195
10	0.227
11	0.312
12	0.336
13	0.363

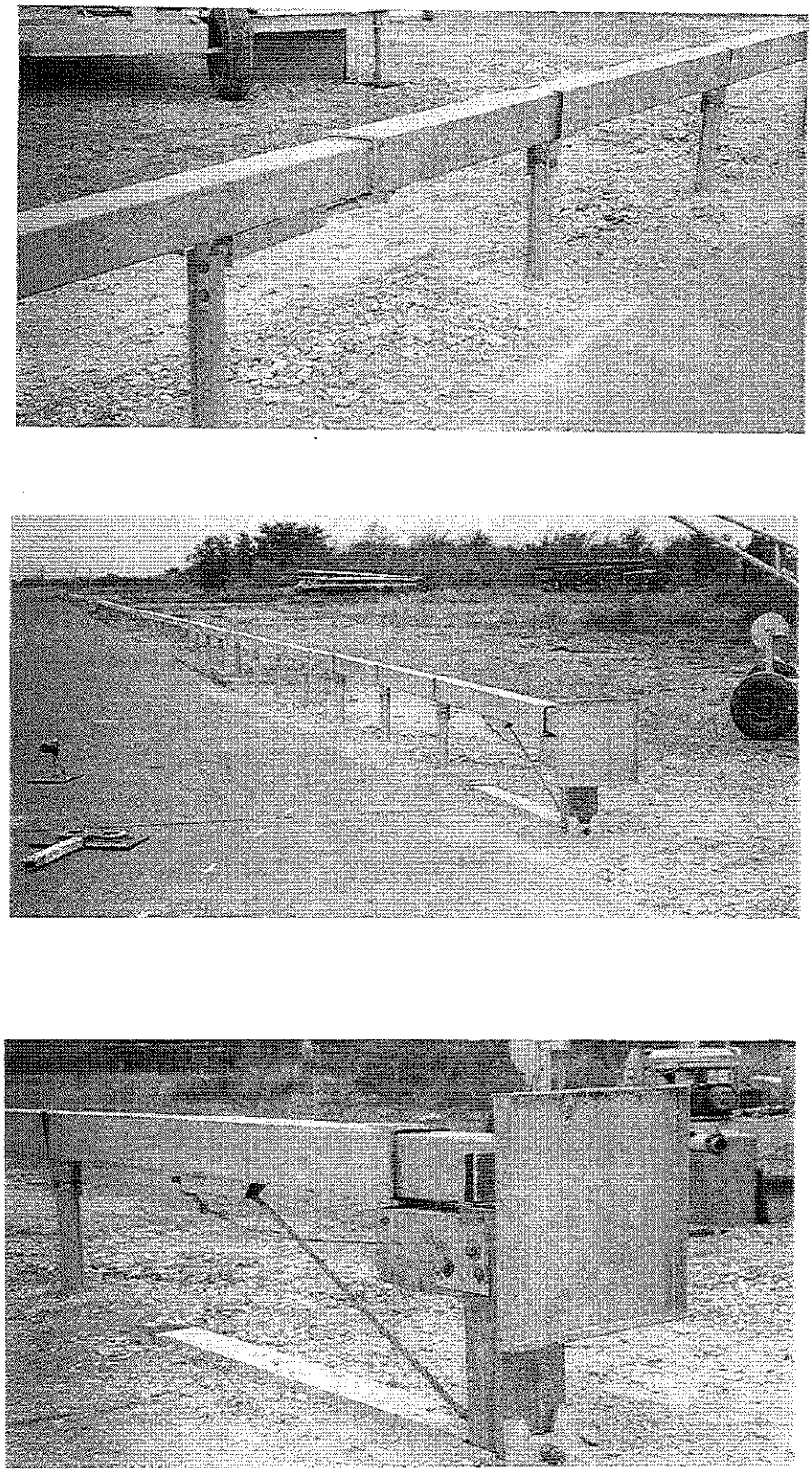
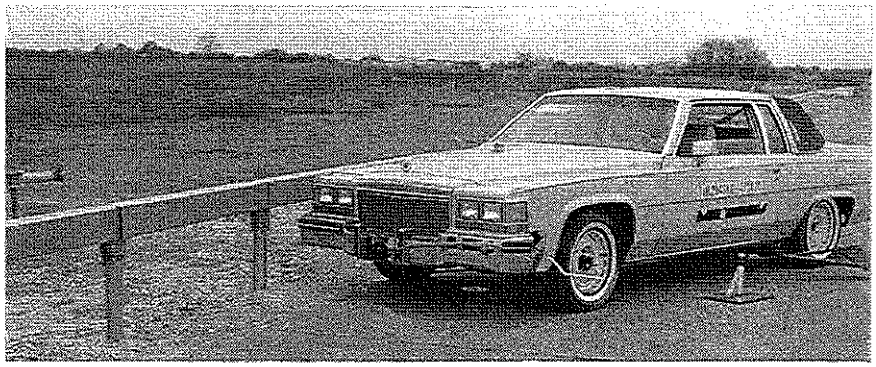
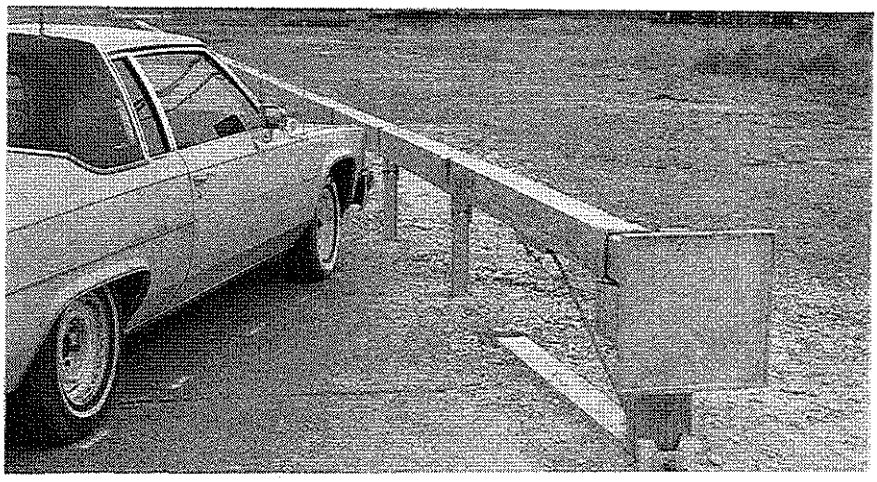


Figure 30. Wyoming box-beam rail installation before test 472020-8.





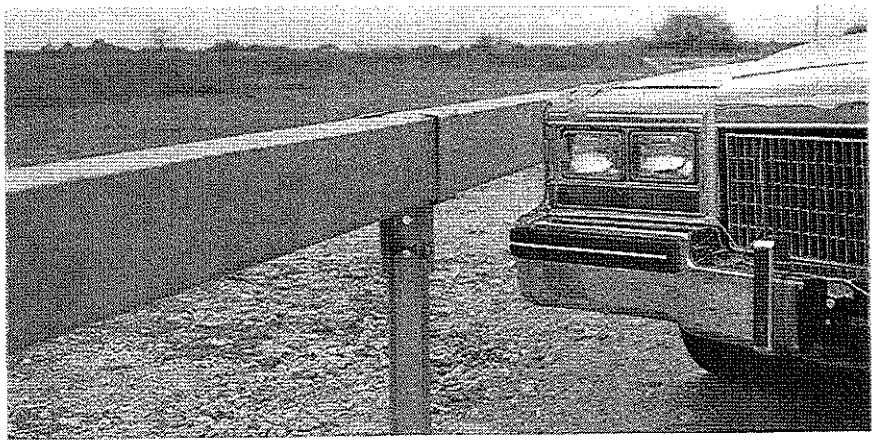


Figure 31. Vehicle/rail geometrics for test 472020-8.

Figure 32. Vehicle before test 472020-8.

DATE: 12-07-93 TEST NO.: 472020-8 VIN NO.6D476A9140748 MAKE: Cadillac

MODEL: Coupe deVille YEAR: 1979 ODOMETER: 10627 TIRE SIZE:R205/75R15

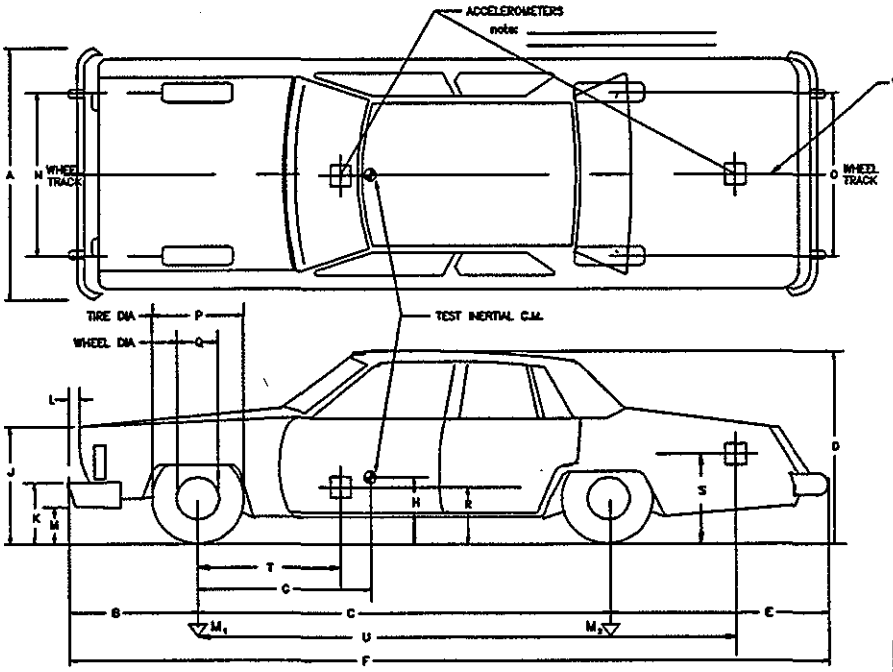
TIRE INFLATION PRESSURE:

MASS DISTRIBUTION (kg) LF 527 RF 532 LR 491 RR 493

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Crack in windshield (marked)

Small dent in right side door (marked)



ENGINE TYPE: V-8

ENGINE CID: 6.0 liter

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

1 mm = 0.039 in
1 kg = 2.202 lb

GEOMETRY – (mm)

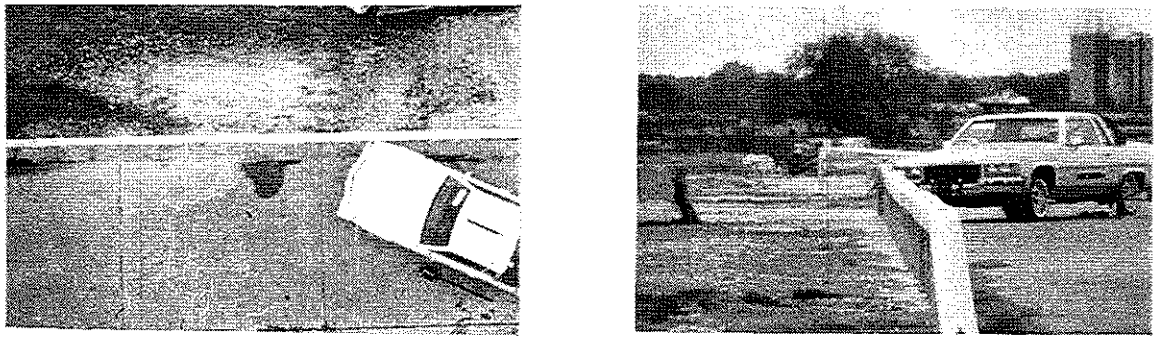
A	1865	E	1470	J	840	N	1589	R	450
B	1070	F	5635	K	515	O	1589	S	810
C	3095	G	1491	L	100	P	670	T	1330
D	1455	H		M	304	Q	415	U	4025

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1084	1059	
M_2	771	984	
M_T	1855	2043	

Figure 33. Vehicle properties for test 472020-8.

The vehicle impacted post 5 at 0.129 second. The wooden end post (post 1) began to rotate clockwise at approximately 0.130 second. The vehicle impacted post 6 at 0.205 second and the vehicle began to move behind the installation near post 7 at approximately 0.286 second. The vehicle was travelling completely behind the original face of the rail by 0.414 second. By 0.454 second, the rear of the vehicle contacted the rail and was traveling parallel to the rail at 44.4 mi/h (71.4 km/h). The maximum dynamic deflection of the rail element was 10.0 ft (3.0 m) at approximately post 9. At approximately 0.451 second, the rail element began to slide off of the top surface of the bumper and fell toward the ground. By 0.641 second, the rail element was on the ground and the vehicle began to traverse the rail element approximately 59.4 ft (18.1 m) downstream from the initial point of impact. At 0.804 second, the right front tire began to climb up and over the rail. The left front tire of the vehicle started climbing over the rail at 1.126 second. The front end of the vehicle became airborne, yawing clockwise, with the right front tire re-contacting the ground at 1.314 second. Simultaneous to the right front tire contacting the ground, the rear of the vehicle impacted the rail and the left rear tire began to jump the rail. The vehicle continued to rotate clockwise as the rear of the vehicle became completely airborne. The lower portion of the left rear quarter panel impacted the top of the rail at 2.120 second, as the rear of the vehicle began to descend. The left rear corner of the bumper thereafter rode along the top of the rail with the rear tires airborne and the vehicle yawing clockwise until approximately 2.949 second, when the vehicle re-contacted the ground. The vehicle exited behind the installation and came to rest 44.7 m (146.6 ft) downstream from the point of impact and 3.7 m (12.0 m) behind the installation. Sequential photographs of the test are shown in Figures 34 and 35.

The test installation sustained considerable damage during the test, as shown in Figure 36. The foundation tube for the wooden end post was pulled out of the ground and displaced laterally approximately 31 in. (787.4 mm). The wooden end post was splintered at the top. The second foundation tube was displaced laterally 3.5 in. (89.0 mm) and the ground channel strut was twisted due to the upward movement of the foundation tube for the wooden end post. The outer tube was bent near the downstream end where the standard TS 6-in. x 6-in. x 3/16-in. (152-mm x 152-mm x 4.8-mm) box-beam guardrail rail element was inserted into the outer tube. The standard box-beam guardrail rail element was also slightly bent from impact by the vehicle. Posts 3 through 6 were severely bent from contact with the vehicle. Post 2 and some of the downstream posts were also slightly bent when the rail element became detached from the posts. The detachment of the rail



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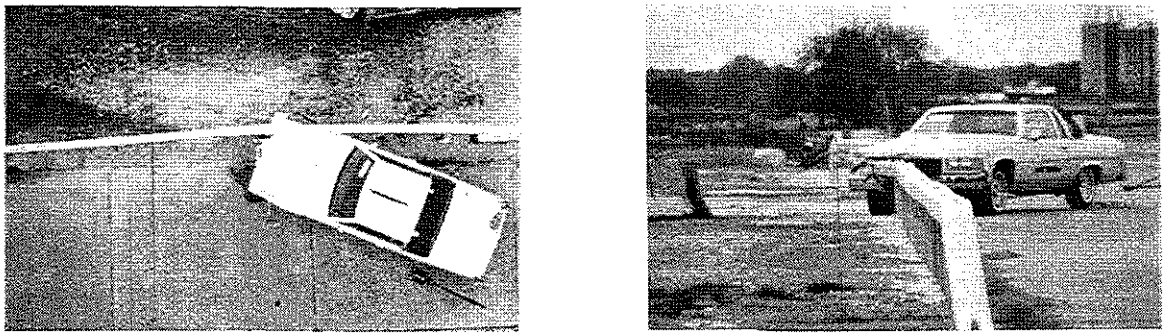
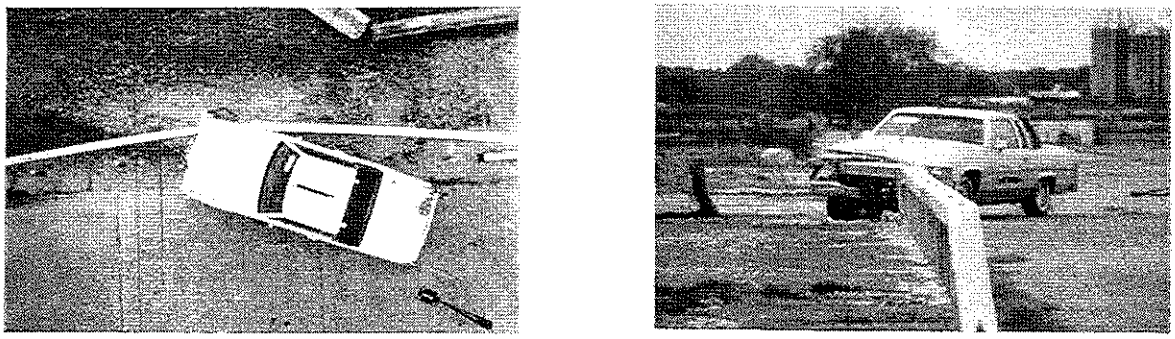
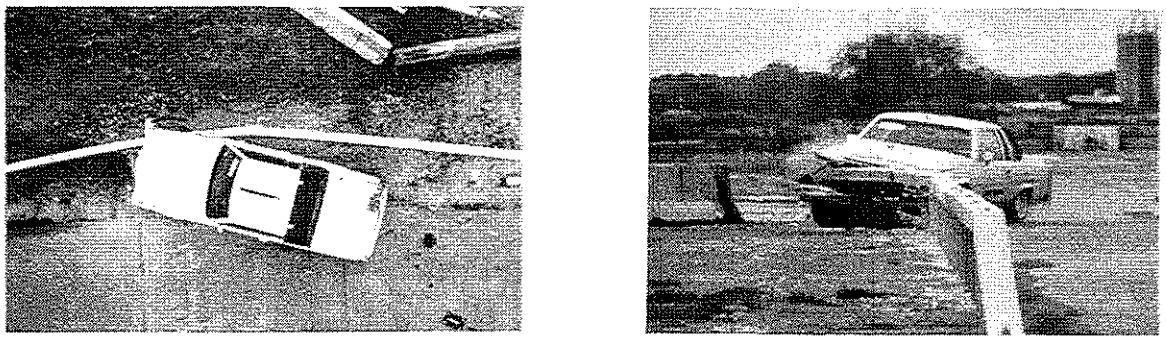


0.071 s

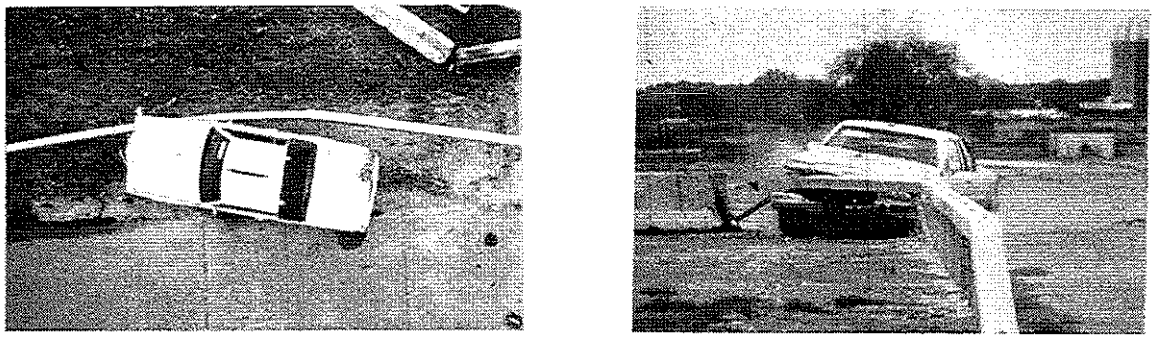


0.142 s

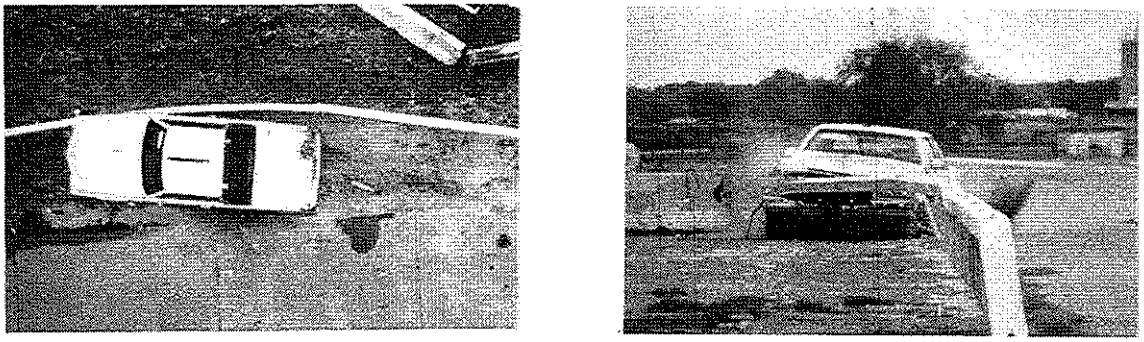


0.213 s

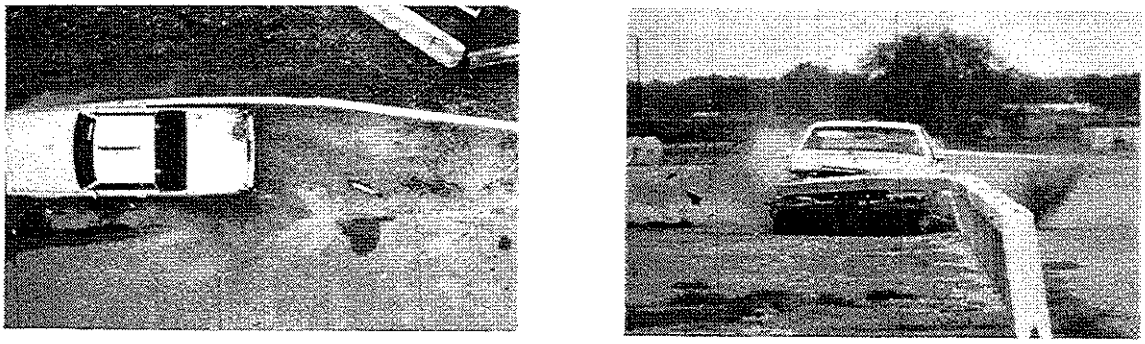
Figure 34. Sequential photographs for test 472020-8.
(overhead and frontal views)



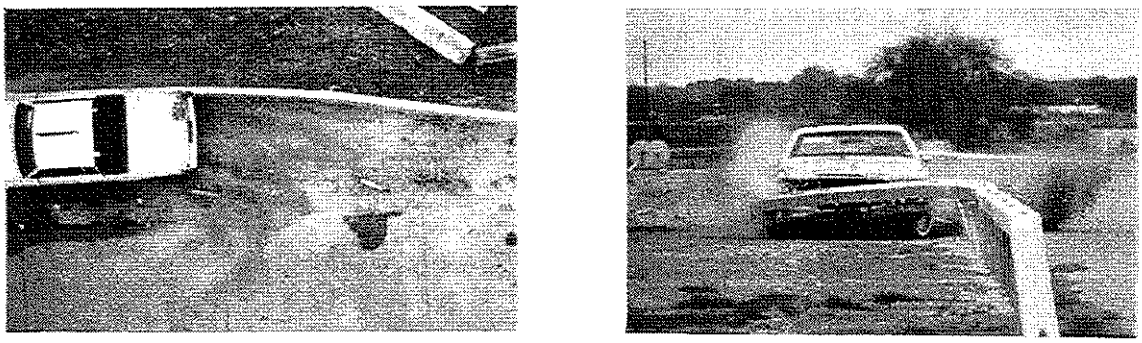
0.284 s



0.355 s

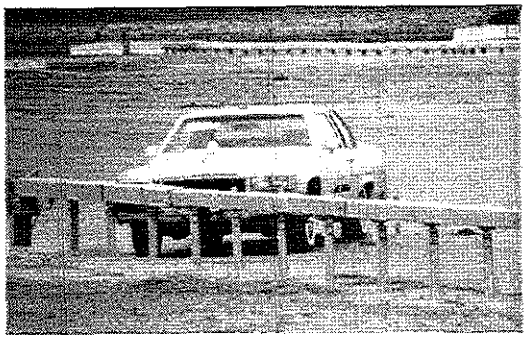


0.426 s

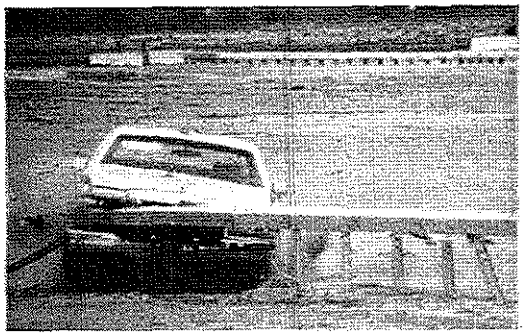


0.497 s

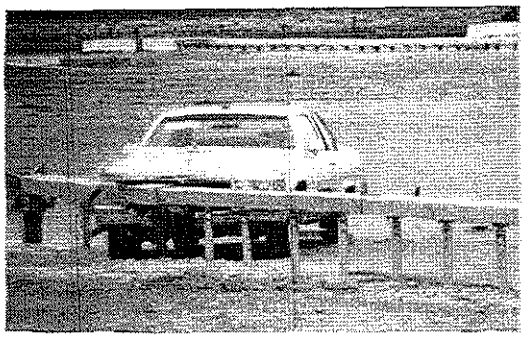
Figure 34. Sequential photographs for test 472020-8 (continued).
(overhead and frontal views)



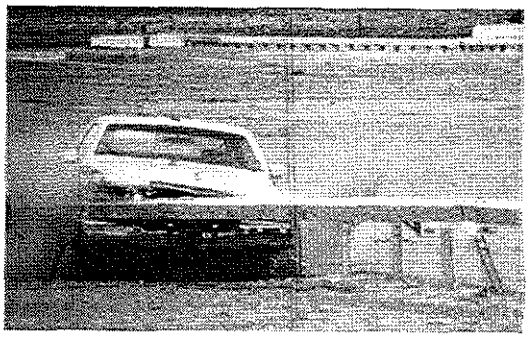
0.000 s



0.284 s



0.071 s



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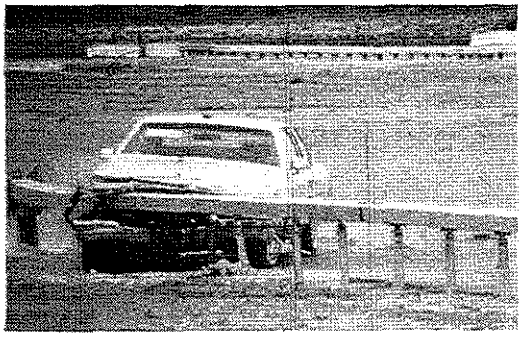

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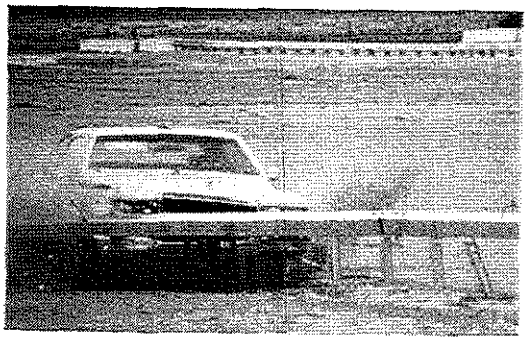
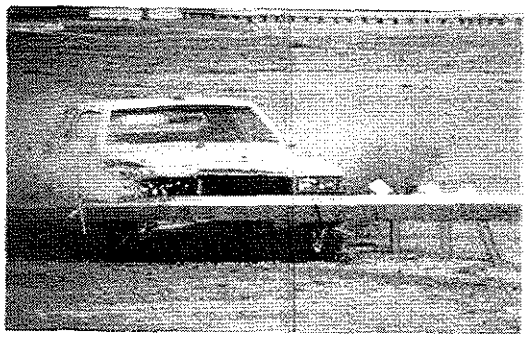


0.426 s

0.213 s



0.497 s

Figure 35. Sequential photographs for test 472020-8.
(behind the rail view)

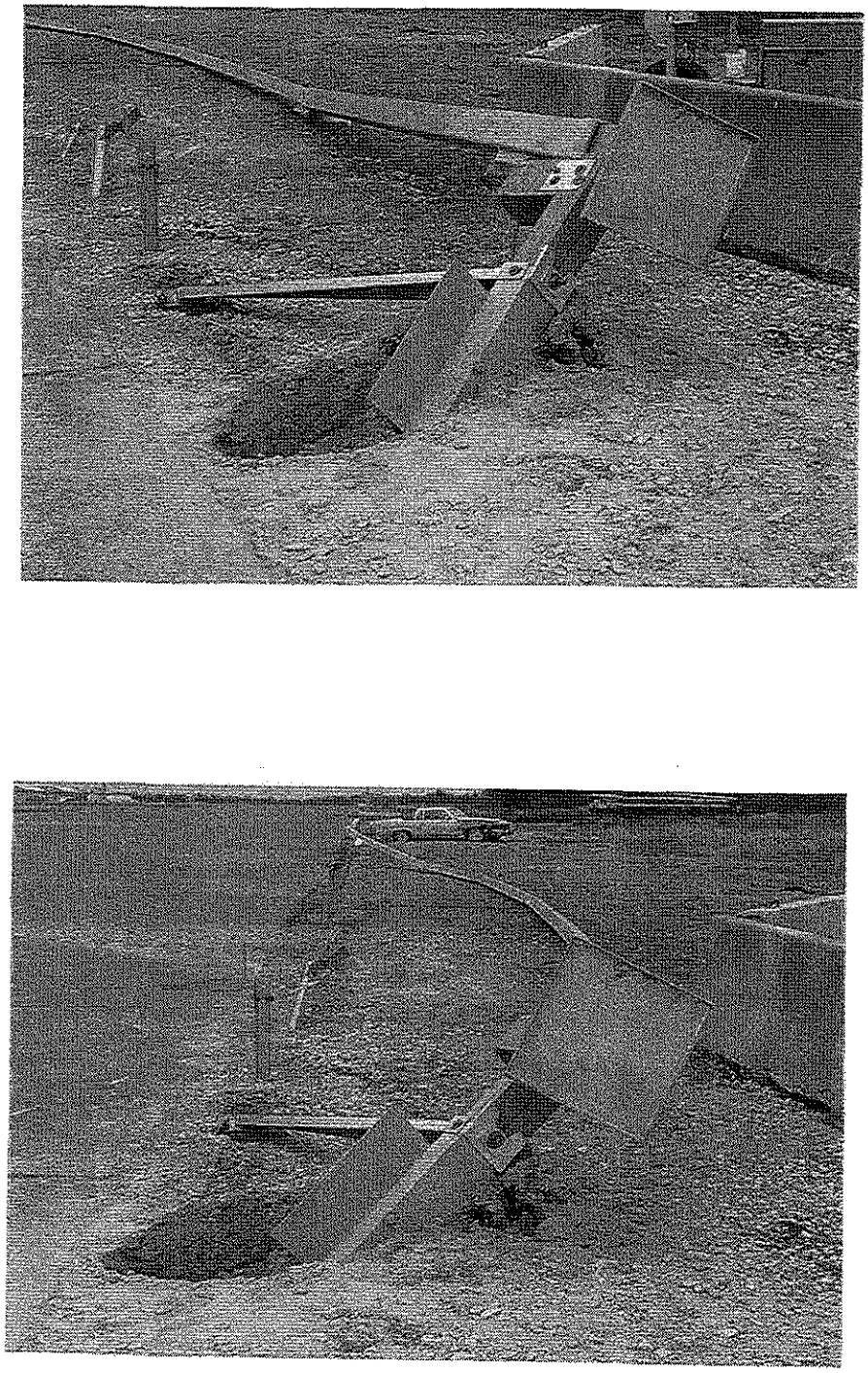


Figure 36. Wyoming box-beam rail installation after test 472020-8.

element from the posts resulted in bending of the shelf angles for posts 2 through 4, shearing of the bolts at posts 6 through 8, and bending and twisting of the paddles for the downstream posts. The maximum permanent rail deflection was the same as the dynamic rail deflection which was 10.0 ft (3.0 m) at approximately post 9. The vehicle was in contact with the installation for a total length of 136.6 ft (41.6 m).

The vehicle received moderate damage, as shown in Figure 37. The damage sustained was concentrated at the right front quarter of the vehicle. Maximum crush was 13.4 in. (340 mm) at the right front corner of the vehicle. The right front of the frame and control arm were bent. Most all the body panels on the right side were scraped and deformed forward of the rear axle. However, there was no intrusion into the occupant compartment.

Although not required as part of the evaluation criteria, data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 15.2 ft/s (4.6 m/s), the highest 0.010-second average ridedown acceleration was -2.4 g and the maximum 0.050-second average acceleration was -2.3 g. In the lateral direction, occupant impact velocity was 8.8 ft/s (2.7 m/s), the highest 0.010-second average ridedown acceleration was -3.9 g and the maximum 0.050-second average lateral acceleration was -2.2 g. These data and other pertinent information from the test are summarized in Figure 38. Vehicular angular displacements are displayed in Figure 39. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 40 through 42.

In summary, the barrier is judged to have performed unsatisfactorily in this length-of-need strength test. The anchorage failed in the test with the foundation tube for the end post being pulled out from the ground. The loss of anchorage capacity resulted in excessive dynamic deflection of the rail element, allowing the rail element to disengage from the vehicle and drop to the ground. The vehicle then mounted and went over the rail element and penetrated behind the barrier.

The coverage of the high-speed cameras did not provide a good view of the anchorage assembly and there was insufficient information to determine how the anchorage assembly failed. There are a number of possible causes for the failure of the anchorage assembly, such as lack of lateral stiffness for the median barrier and/or poor compaction of the soil around the wooden end post foundation tube. While it was not possible to pinpoint the exact causes for the failure of the

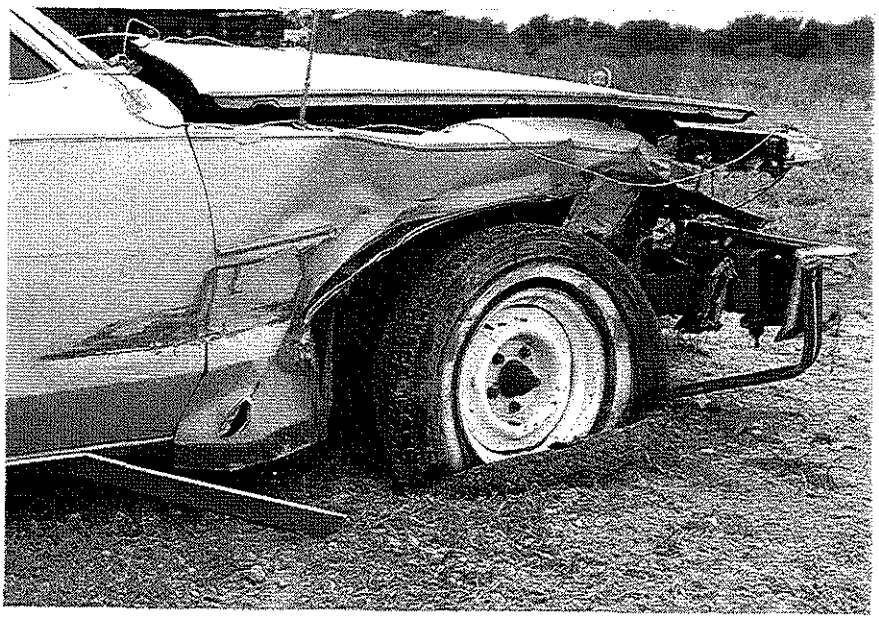
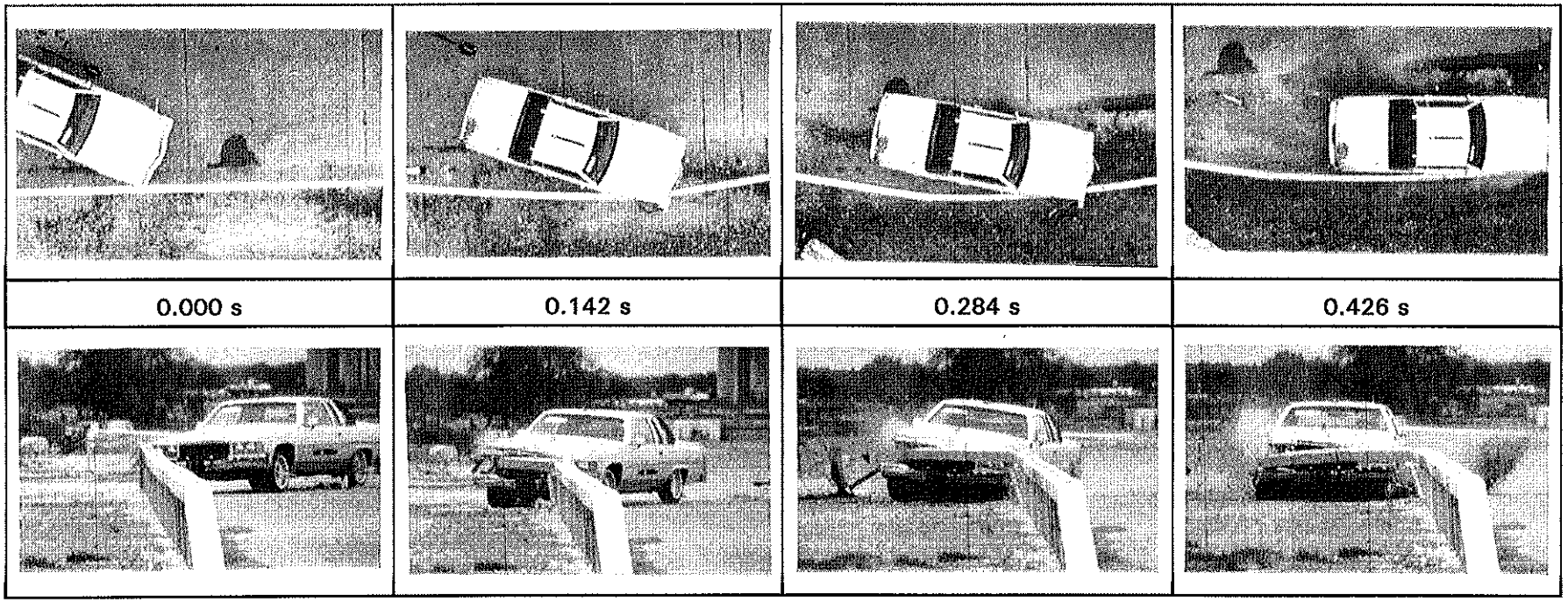
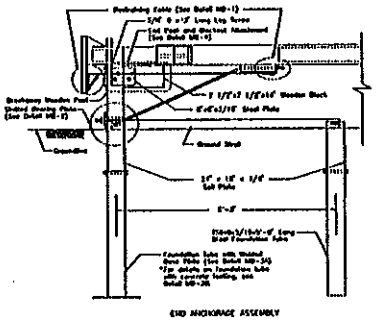


Figure 37. Vehicle after test 472020-8.





Test No.	472020-8	Impact Speed	60.2 mi/h (96.9 km/h)
Date	12/07/93	Impact Angle	25.1 degrees
		Speed at Parallel	N/A
Test Installation	Wyoming Box-Beam End Terminal	Exit Speed	N/A
		Exit Trajectory	N/A
Installation Length	217 ft (66.1 m)	Vehicle Accelerations (Max 50-ms Avg)	
Test Vehicle	1979 Cadillac Coupe De Ville	Longitudinal	-2.3 g
		Lateral	-2.3 g
Vehicle Weight		Occ. Impact Velocity	
Test Inertia	4504 lb (2043 kg)	Longitudinal	15.2 ft/s (4.6 m/s)
Gross Static	4504 lb (2043 kg)	Lateral	8.8 ft/s (2.7 m/s)
Vehicle Damage Classification		Occ. Ridedown Acc.	
TAD	01RFQ4	Longitudinal	-2.4 g
CDC	01FREK2 & 01RYEW3	Lateral	-3.9 g
Maximum Vehicle Crush	9.8 in (249 mm)		

Figure 38. Summary of results for test 472020-8.

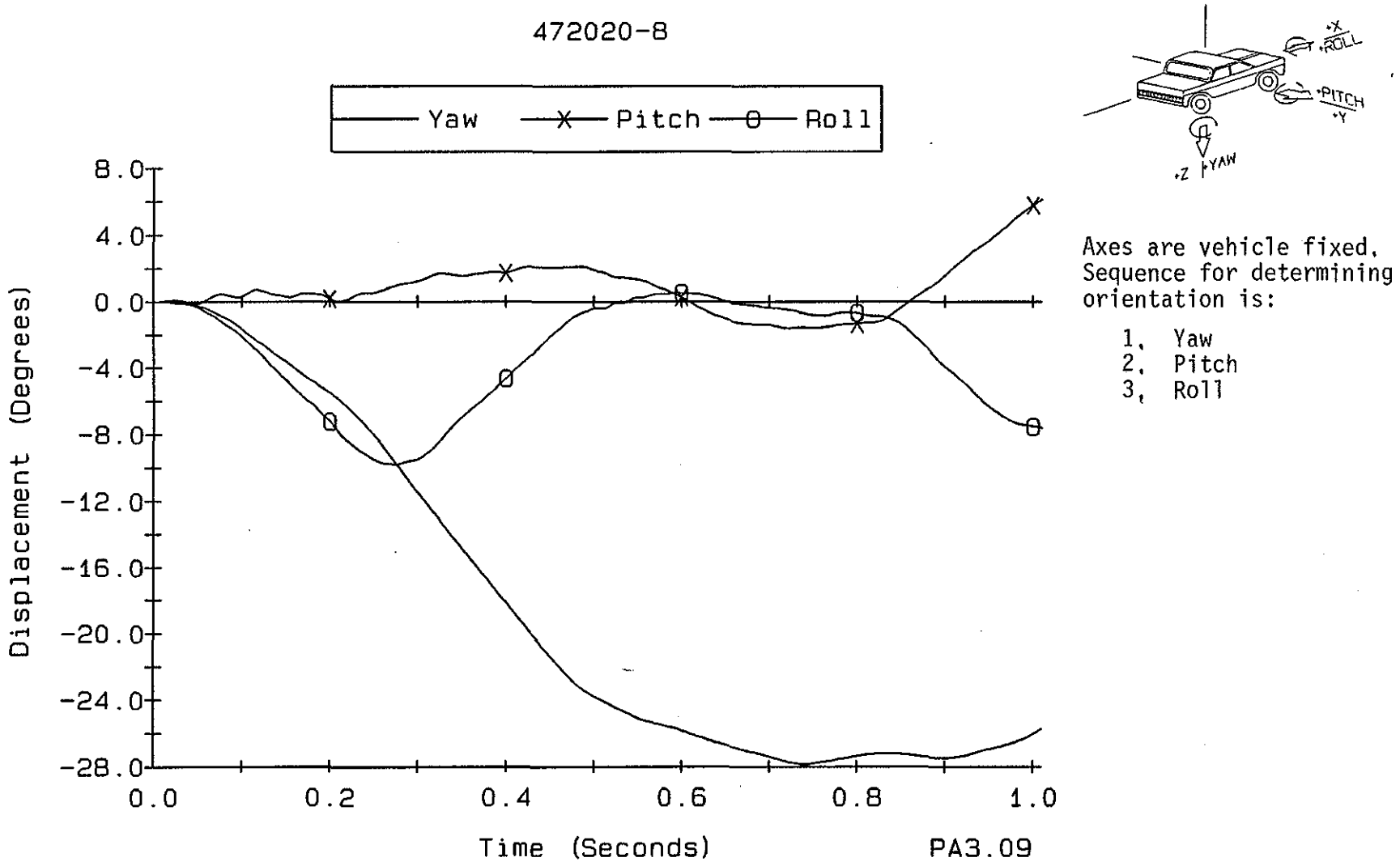


Figure 39. Vehicle angular displacements for test 472020-8.

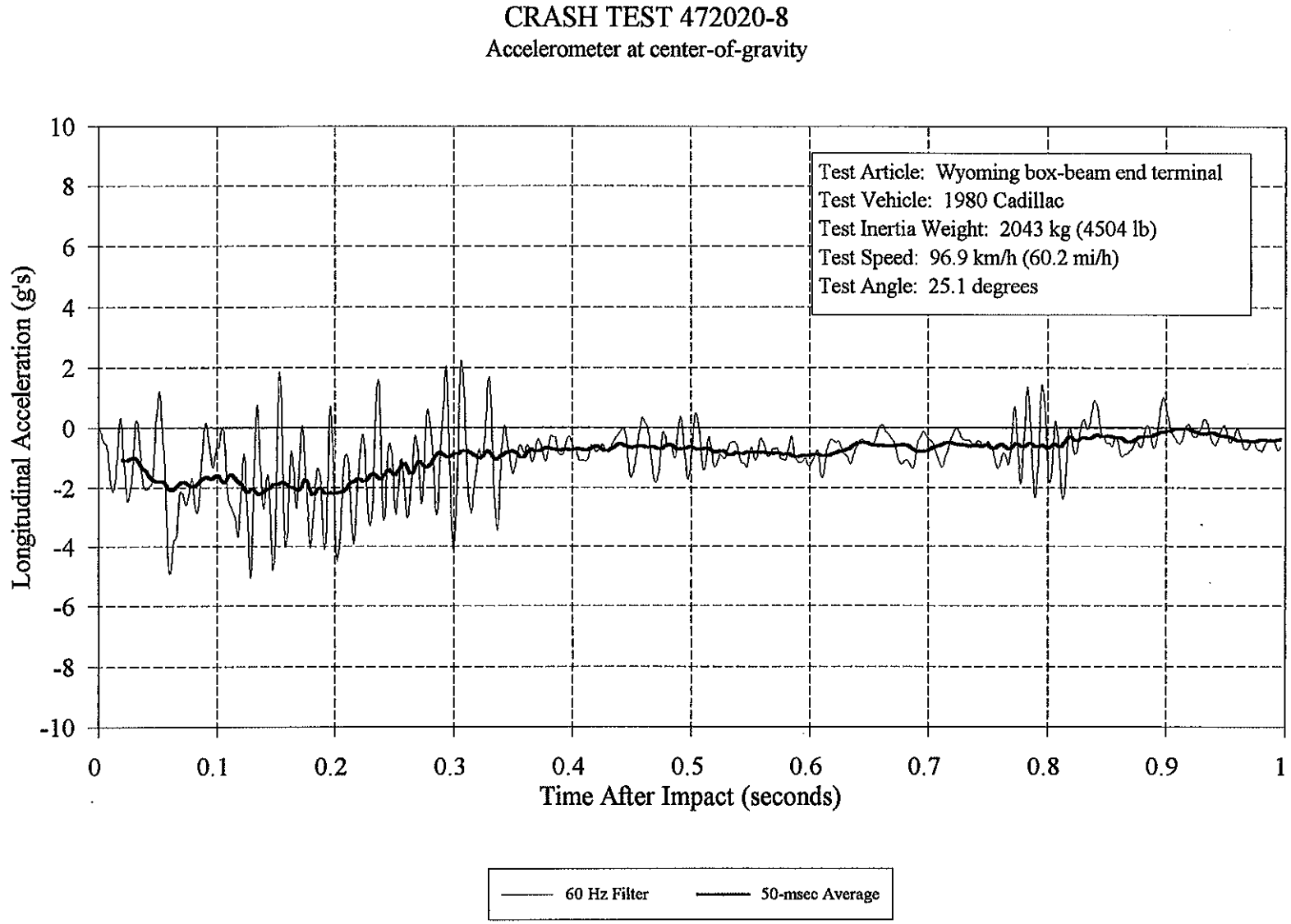


Figure 40. Vehicle longitudinal accelerometer trace for test 472020-8.

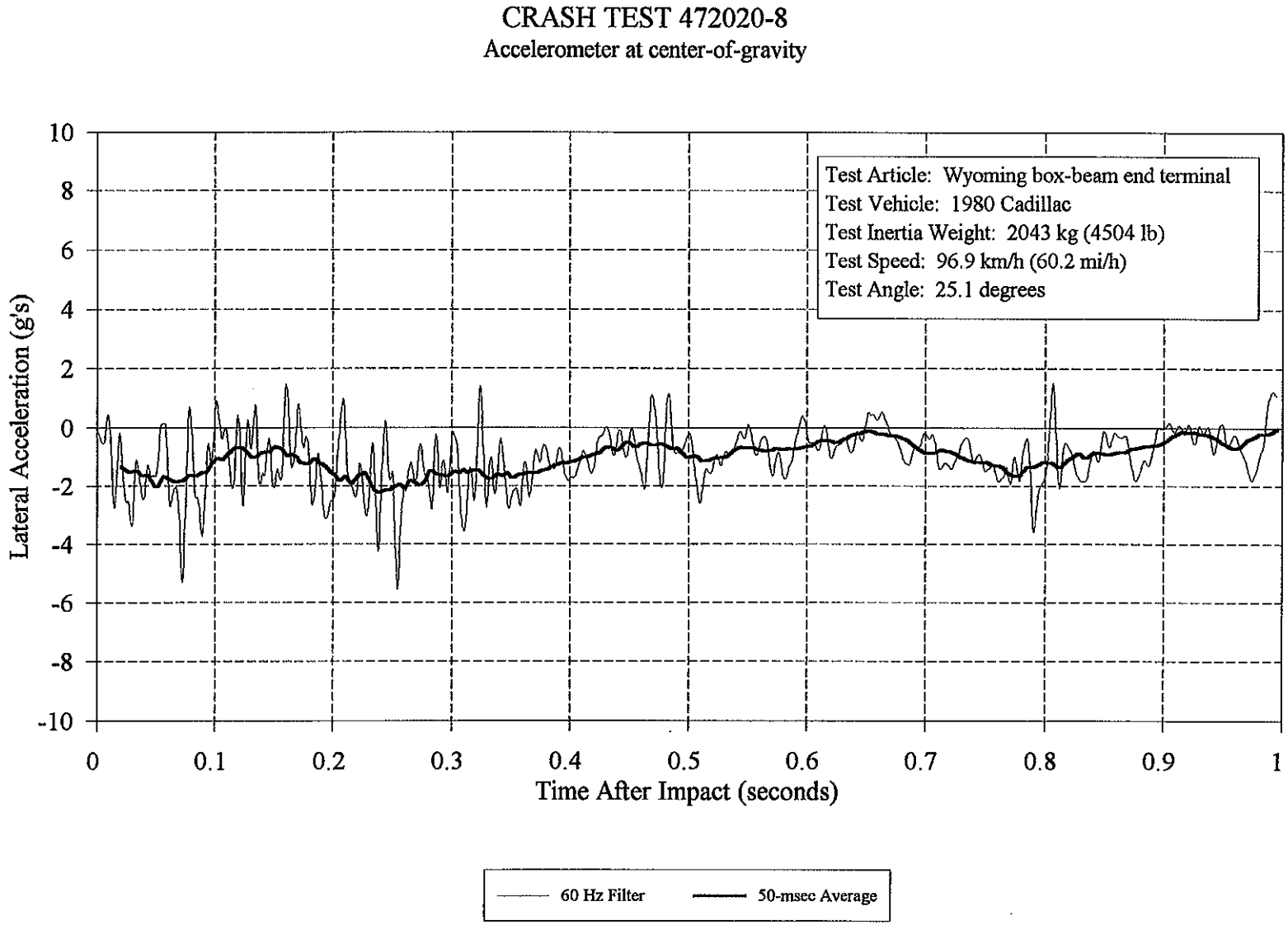


Figure 41. Vehicle lateral accelerometer trace for test 472020-8.

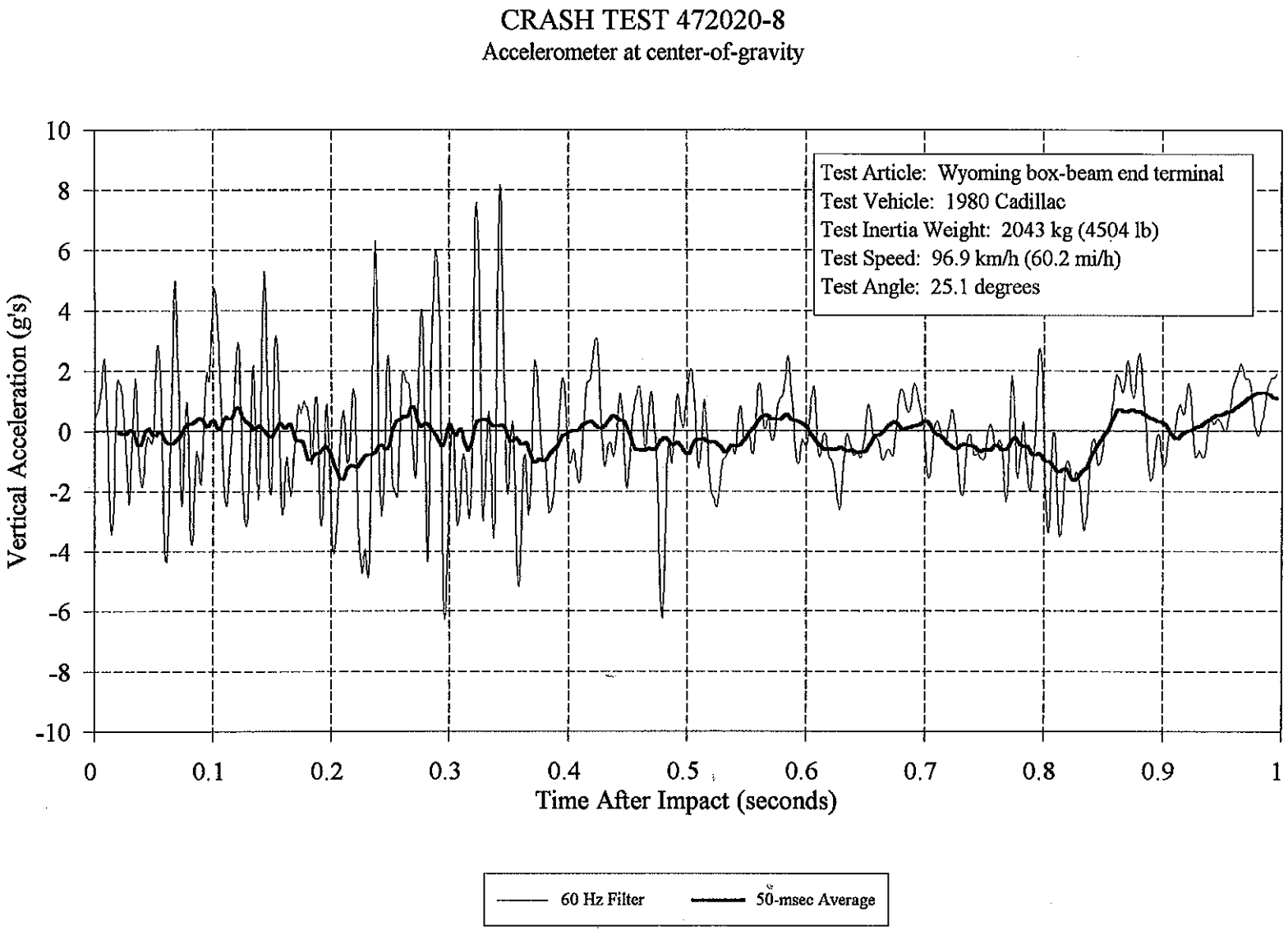


Figure 42. Vehicle vertical accelerometer trace for test 472020-8.

anchorage assembly, the problem can be remedied by increasing the anchorage capacity of the end terminal. Three alternatives were proposed to the Wyoming Department of Transportation for consideration:

1. Increase the embedment length of the end post foundation tube.
2. Weld a large end plate to the bottom of the end post foundation tube.
3. Embed the end post foundation tube in concrete.

After further discussions with the Department, it was decided to delete the alternative of increasing the embedment depth of the end post foundation tube from further consideration due to anticipated field installation problems. The Department would like to have the option of using either one of the two remaining alternatives, i.e., embed the end post foundation tube in concrete or weld an end plate to the end post foundation tube. It was therefore decided that designs for both alternatives would be developed, but the base plate alternative, which is the weaker anchorage system, would be crash tested. The rationale is that if the weaker anchorage system performs satisfactorily, the stronger anchorage system should also provide acceptable performance.

4.4 Repeat of Large Car Length-of-Need Strength Test (Test No. 472020-9)

The test installation was repaired and reconstructed with the base plate anchorage assembly design (shown in Figure 43) and the large car length-of-need test was repeated. A 1982 Cadillac Coupe DeVille (shown in Figures 44 and 45) was used with the test. Both the test inertia mass (empty weight) and the gross static mass (test weight) of the vehicle were 4,504 lb (2,043 kg). The heights to the upper and lower edges of the vehicle bumper were 20.3 in. (515.0 mm) and 12 in. (305 mm), respectively. Other dimensions and information on the vehicle are given in Figure 46. The vehicle was directed into the test installation using a cable reverse tow and guidance system and was free wheeling and unrestrained just prior to impact.

The vehicle impacted the box-beam median barrier end terminal at post 3 (beginning of length-of-need) traveling at a speed of 61.2 mi/h (98.5 km/h) and at an angle of 25.4 degrees. Upon impact, post 3 was pushed aside by the corner of the vehicle bumper and the vehicle bumper underrode the rail and began to deflect the rail laterally away from the posts. Post 4 was struck by the front bumper of the vehicle at 0.032 second and by the right front tire at 0.059 second. Post 5 was impacted by

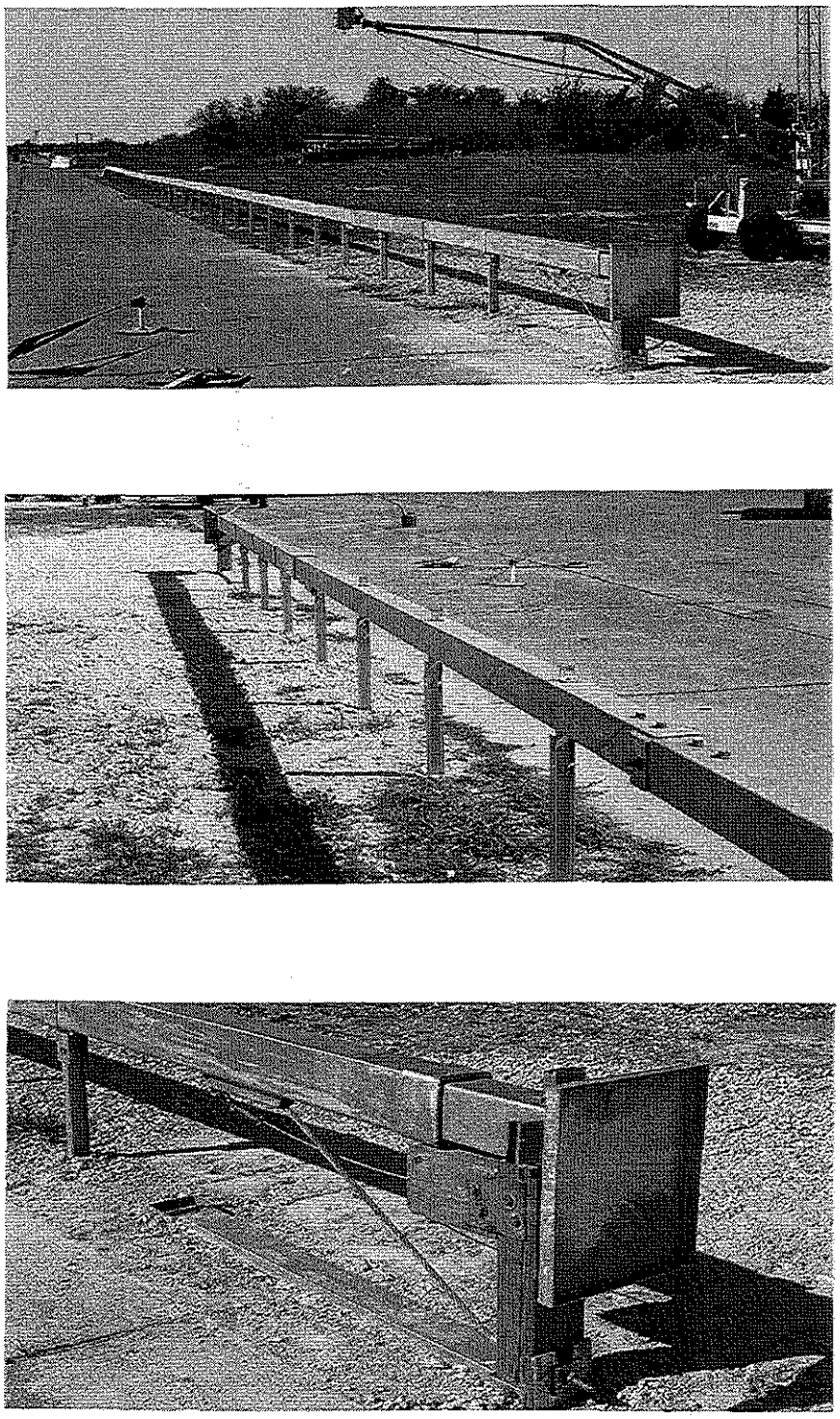
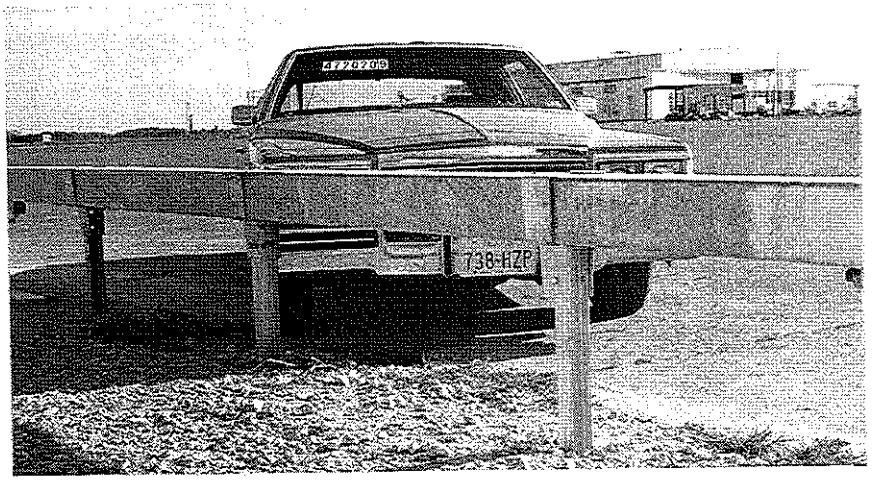
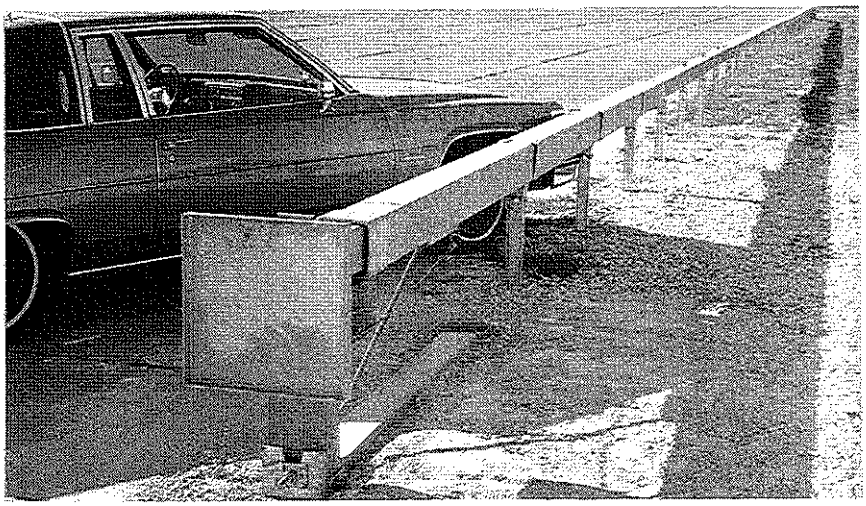


Figure 43. Wyoming box-beam rail installation before test 472020-9.





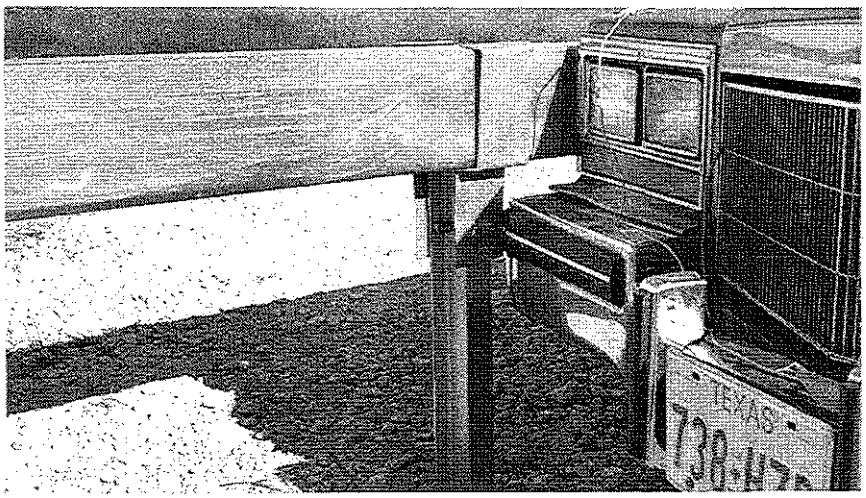


Figure 44. Vehicle/rail geometrics for test 472020-9.

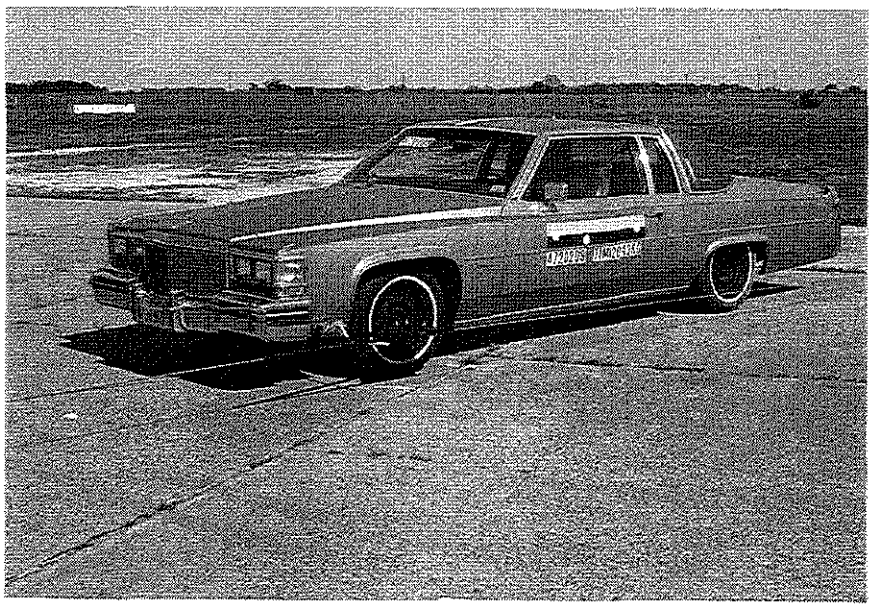


Figure 45. Vehicle before test 472020-9.

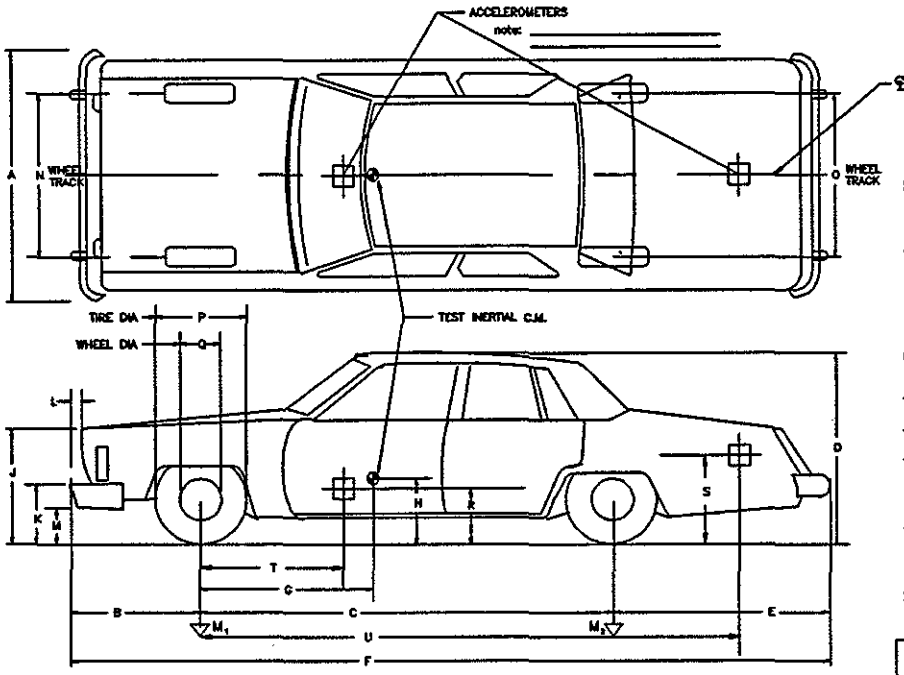
DATE: 3-29-94 TEST NO.: 472020-9 VIN NO.: 1G6AD4737C9123725 MAKE: Cadillac

MODEL: Coupe YEAR: 1982 ODOMETER: 21115 TIRE SIZE: 215/75R15

TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF 508 RF 498 LR 525 RR 512

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: 8 cyl gas

ENGINE CID: 4.1 liter

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

_____

_____

_____

DUMMY DATA:

TYPE: _____

MASS: _____

SEAT POSITION: _____

1 mm = 0.039 in
1 kg = 2.202 lb

GEOMETRY – (mm)

A	1870	E	1460	J	840	N	1570	R	400
B	1020	F	5560	K	515	O	1540	S	705
C	3080	G	1563	L	120	P	710	T	1340
D	1390	H		M	305	Q	415	U	4060

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	979	1006	
M_2	759	1037	
M_T	1738	2043	

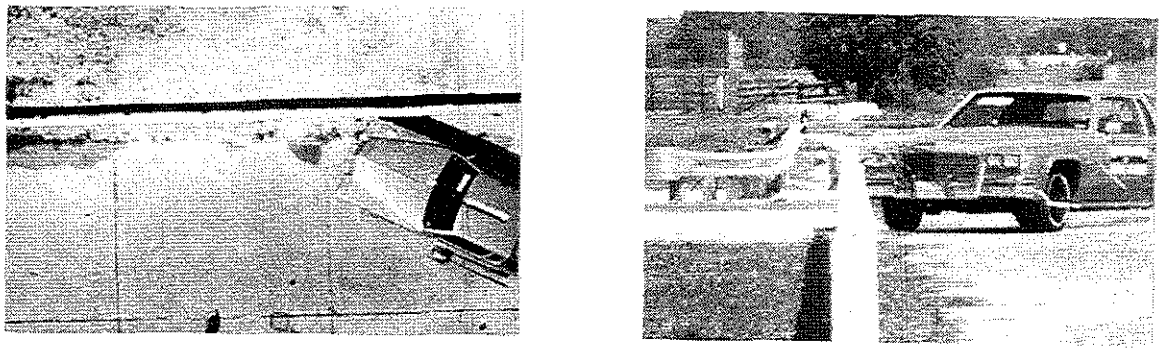
Figure 46. Vehicle properties for test 472020-9.

the vehicle at 0.123 second. As the vehicle was redirected by the installation, the rail element continued to deflect laterally and posts began to separate from the rail element ahead of the vehicle trajectory. The separation of the posts from the rail element propagated down the installation ahead of the vehicle trajectory until all of the posts in the median barrier length-of-need section were eventually detached from the rail element.

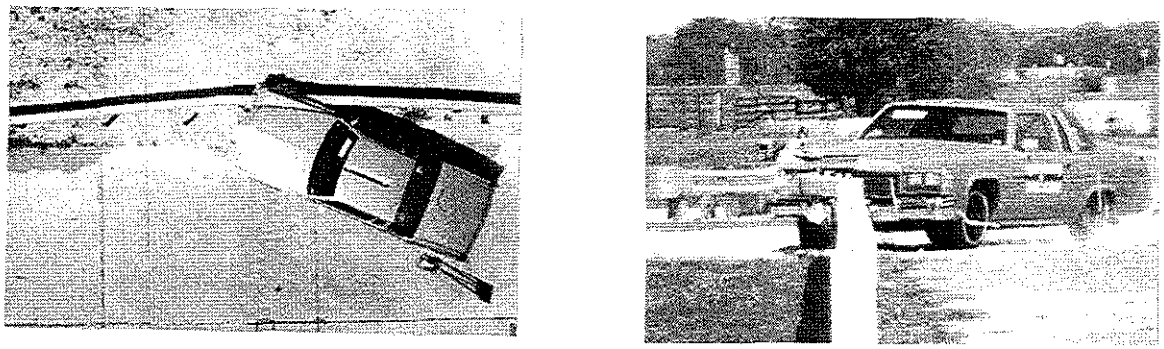
The vehicle began to move beyond the face of the original installation as the vehicle brushed post 6 at approximately 0.191 second. By 0.370 second, the rear of the vehicle contacted the rail element and was traveling parallel to the rail at 44.4 mi/h (71.4 km/h). Maximum dynamic deflection was 7.8 ft (2.4 m) near post 9. The vehicle continued to redirect and the right rear of the vehicle began to ride on top of the rail at 0.383 second. Shortly thereafter, the left front of the vehicle began impacting the free-standing posts that were already separated from the rail element. The vehicle began to turn back toward the rail at 0.674 second. The left rear quarter-panel of the vehicle began impacting posts 15 and 16 at 1.534 second. The right front tire began to climb the rail element, now resting on the ground, and went over the rail element at 1.606 second. At 2.172 second, the left front tire struck the rail element on the ground and climbed over the rail. The entire vehicle eventually climbed over the rail element, went behind the installation and came to rest 179.3 ft (54.7 m) downstream from the point of impact and 44 ft (13.4 m) behind the installation. Sequential photographs of the test are shown in Figures 47 and 48.

Damage sustained to the rail installation during testing is shown in Figure 49. The rail element was detached from all the posts and was lying on the ground. The 6 in. x 6 in. (152 mm x 152 mm) box-beam rail element buckled at 13.0 ft (4.0 m) and 17.1 ft (5.2 m) from the point of initial impact. The end post foundation tube was displaced longitudinally approximately 1.5 in. (38 mm) and the concrete block end anchor at the downstream end was displaced longitudinally approximately 7.5 in. (191 mm). Posts 4, 5 and 6 were severely bent from impact by the front of the vehicle and posts 15 and 16 were bent from impact by the left rear of the vehicle. Posts 3 and 7 through 9 were also bent. The shelf angles at posts 2 through 4 were bent. In addition, many of the paddles in the length-of-need section were twisted and bent when the rail element was detached from the posts. The maximum permanent rail deflection was the same as the dynamic rail deflection which was 7.8 ft (2.4 m) near post 9.

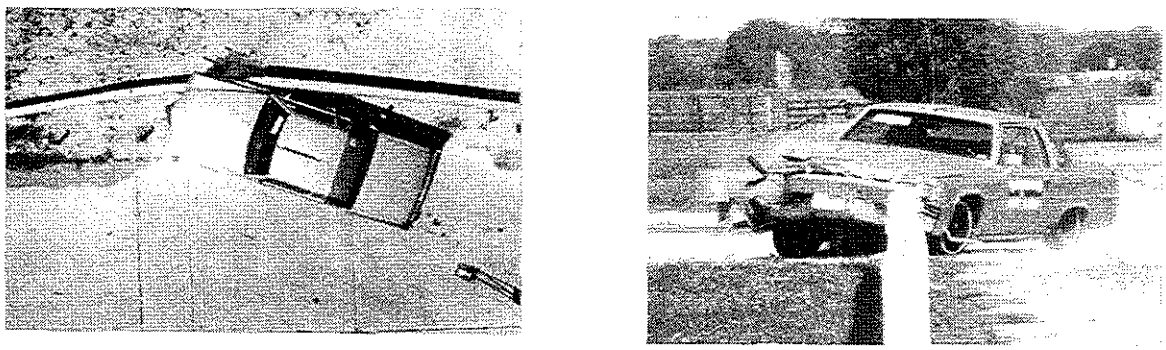
The vehicle received moderate damage, as shown in Figure 50. The damage sustained was concentrated at the right front quarter of the vehicle. Maximum crush was 18.1 in. (460.0 mm) at



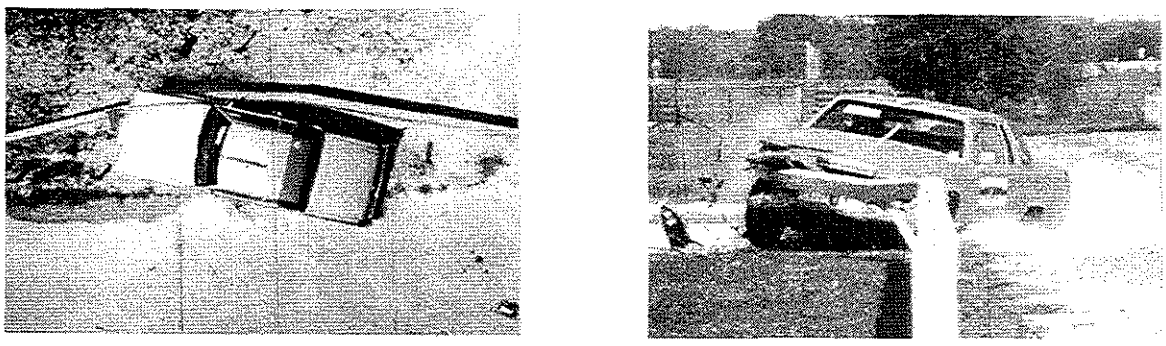
0.000 s



0.085 s

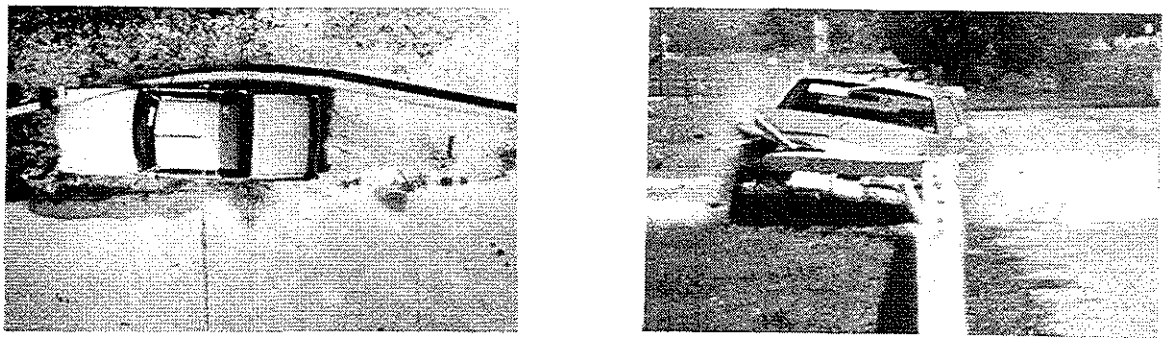


0.169 s

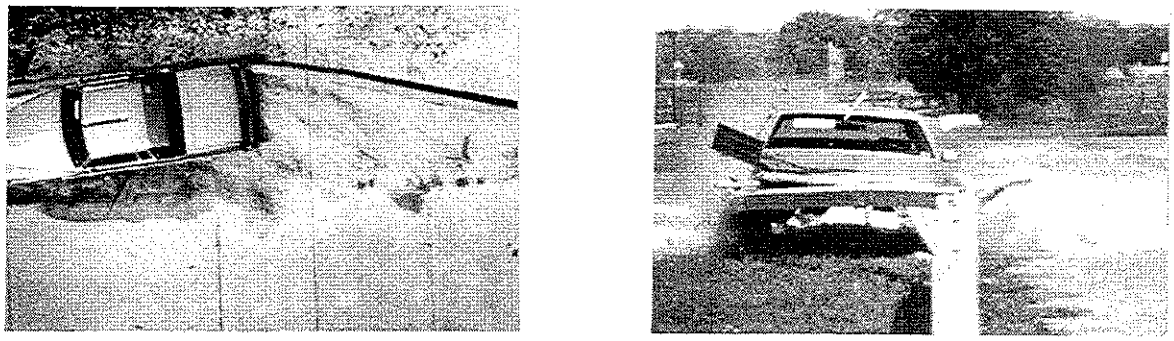


0.254 s

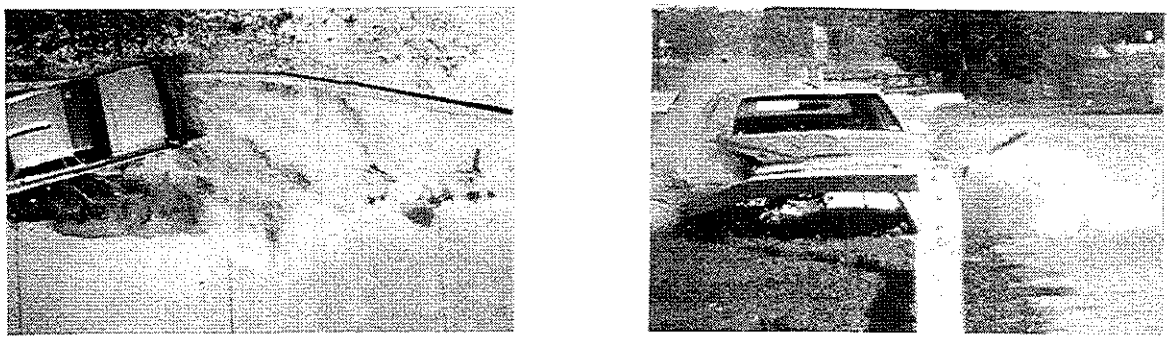
Figure 47. Sequential photographs for test 472020-9.
(overhead and frontal views)



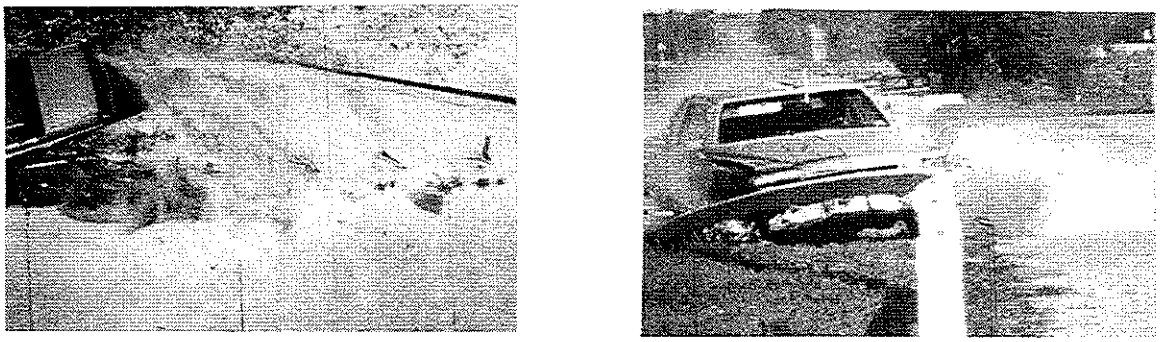
0.339 s



0.424 s

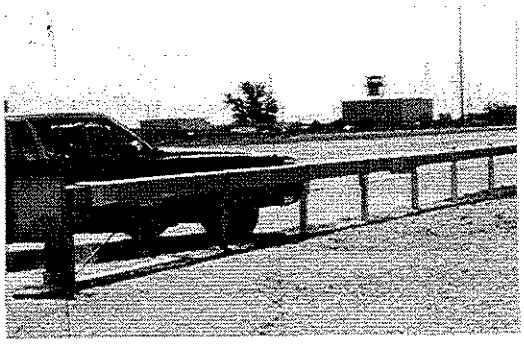


0.508 s

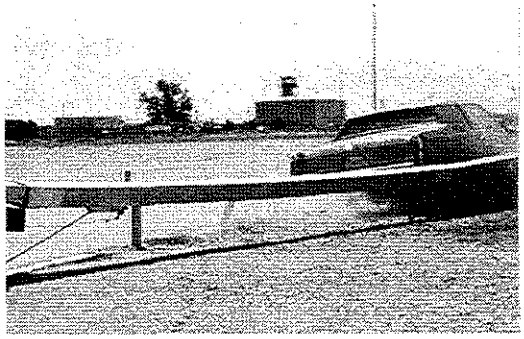


0.593 s

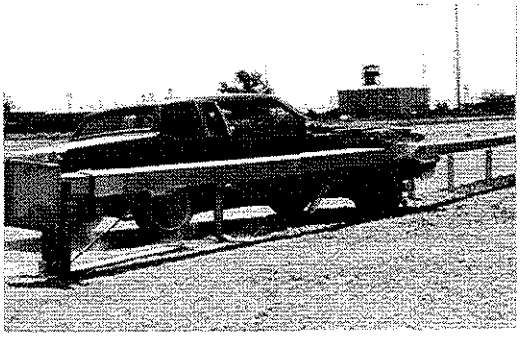
Figure 47. Sequential photographs for test 472020-9 (continued).
(overhead and frontal views)



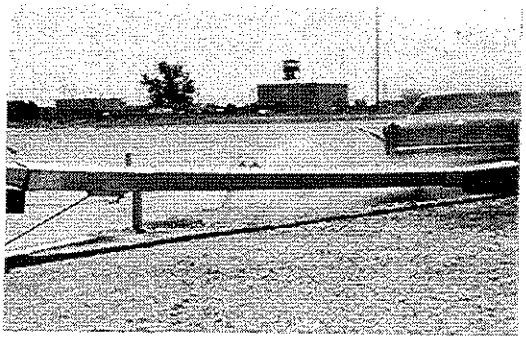
0.000 s



0.339 s

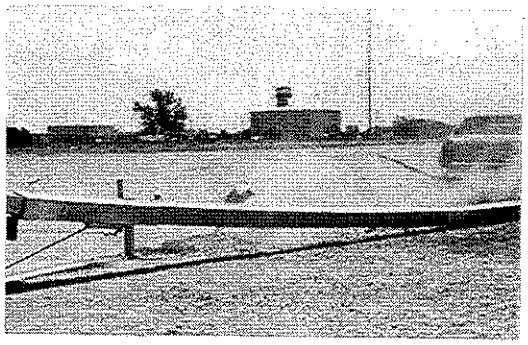


0.085 s

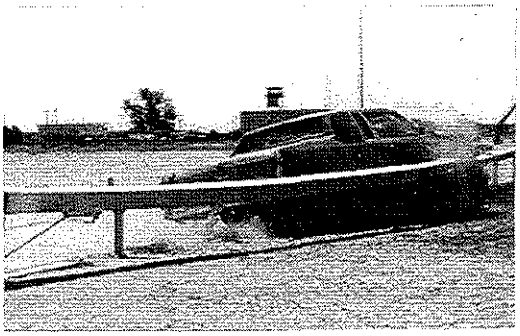


0.424 s

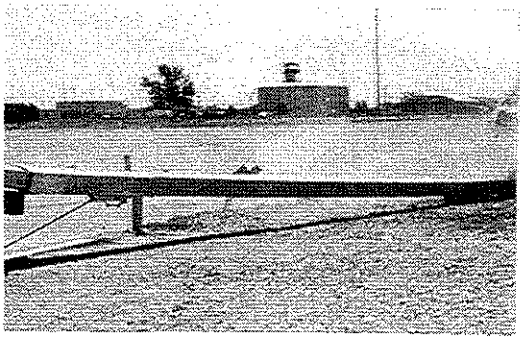
0.169 s



0.508 s



0.254 s



0.593 s

Figure 48. Sequential photographs for test 472020-9.
(behind the rail view)

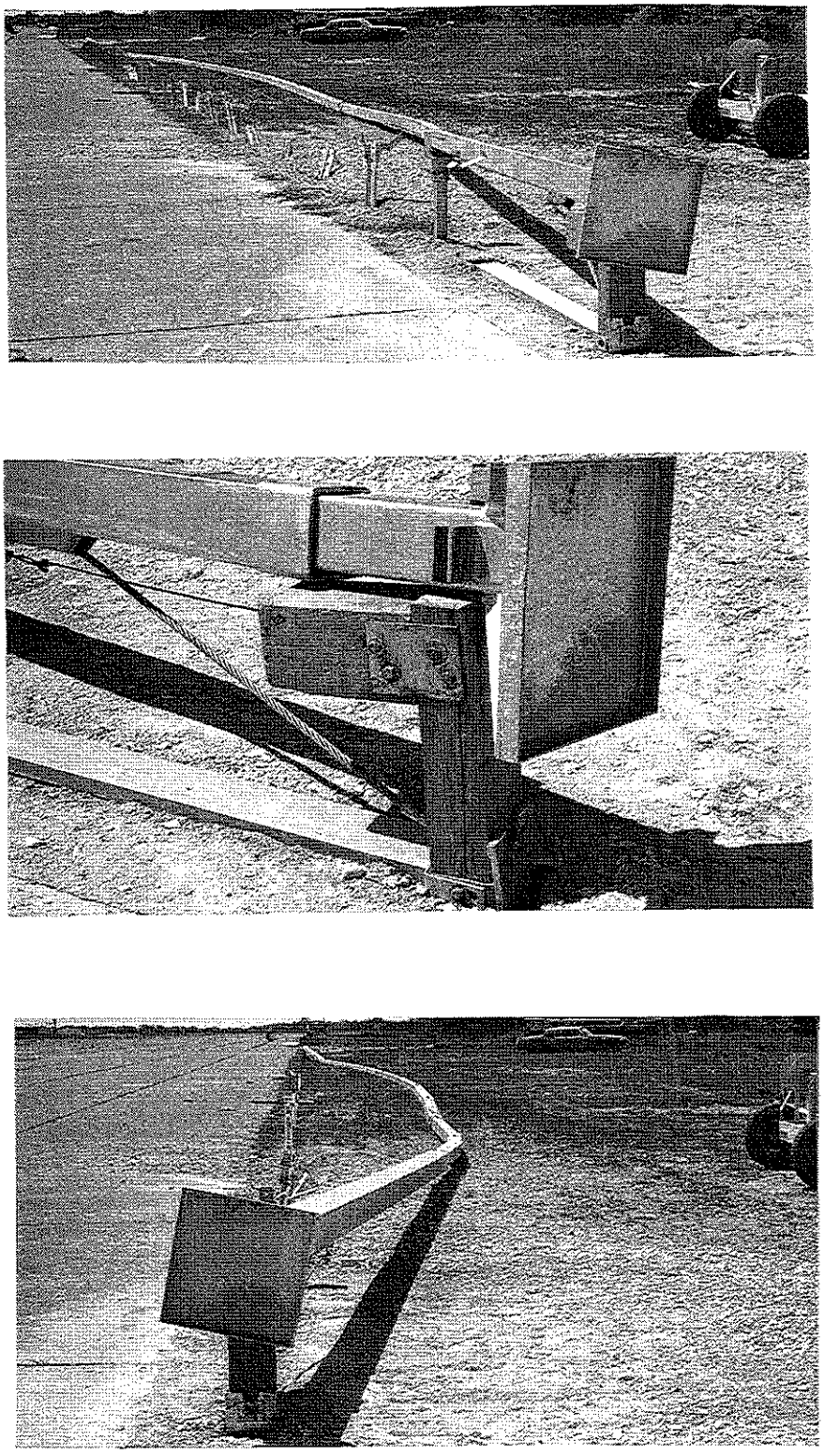
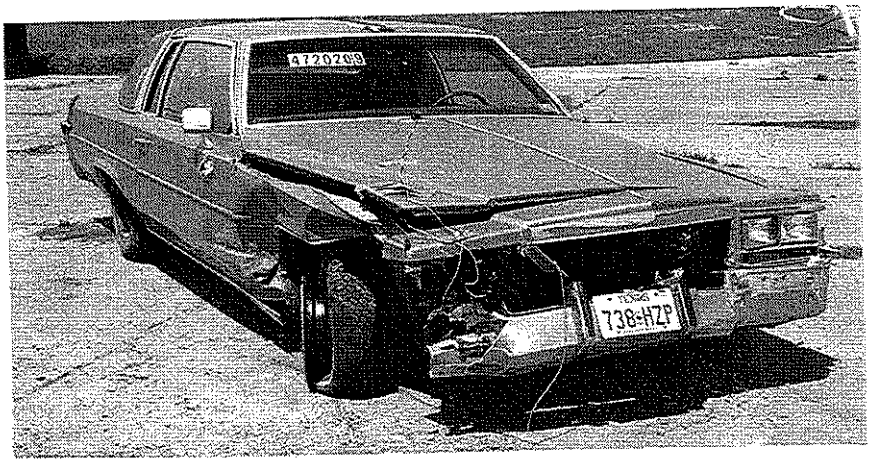


Figure 49. Wyoming box-beam rail installation after test 472020-9.



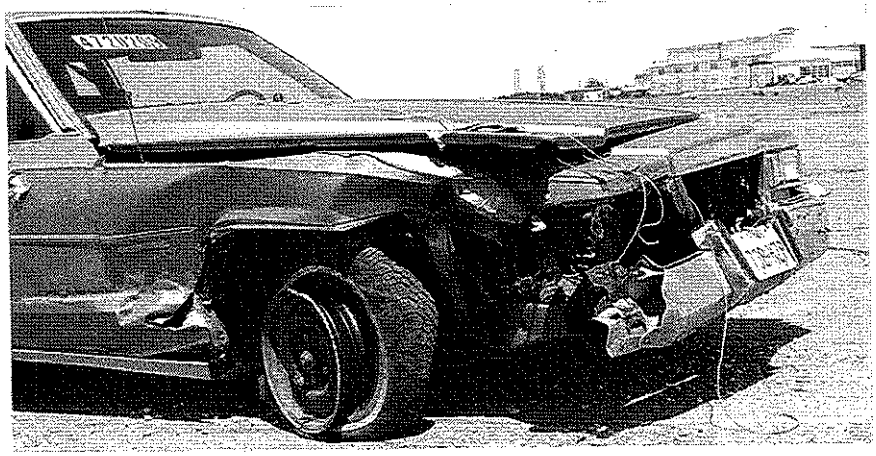


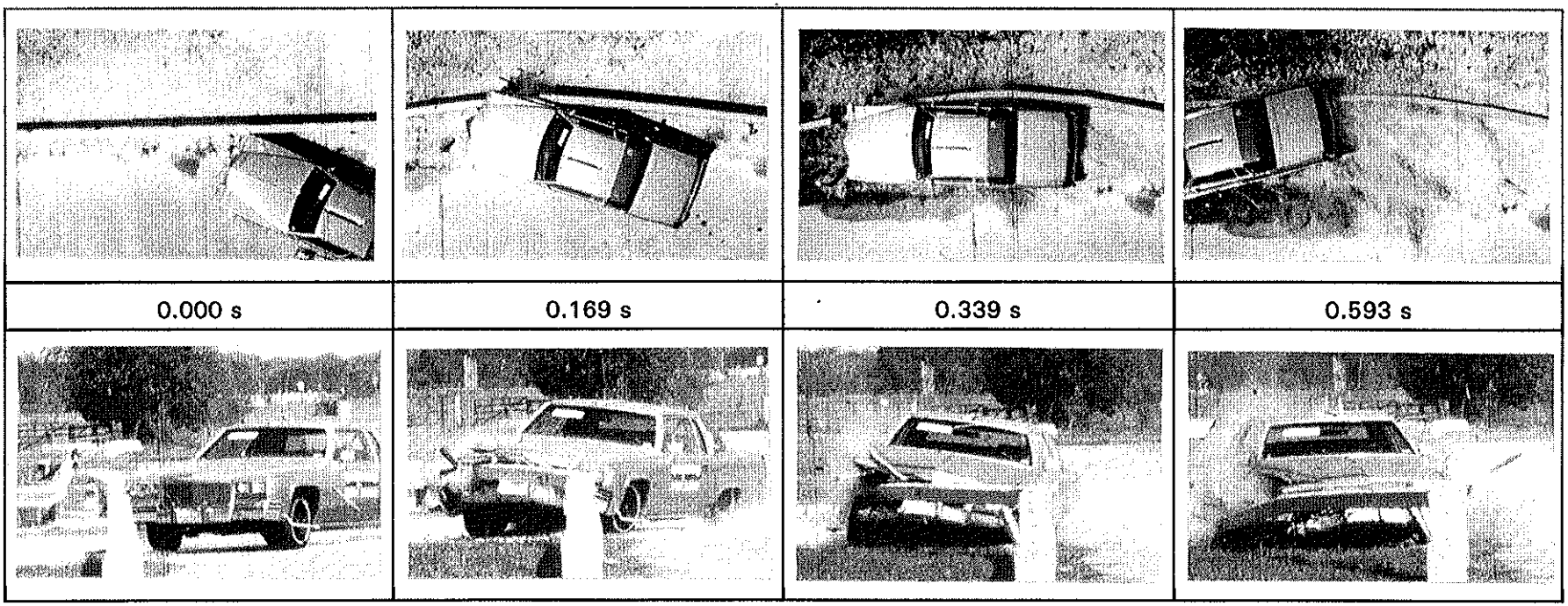
Figure 50. Vehicle after test 472020-9.

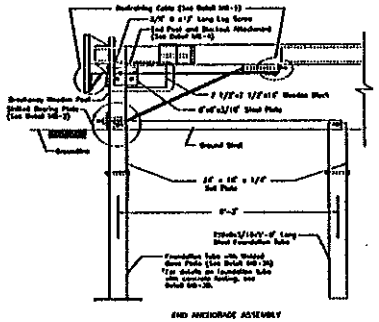
the right front corner of the vehicle. Both the right and left front fenders, wheel rims and doors were bent. In addition, the right rear quarter panel and wheel rim were bent The integrity of the occupant compartment was not violated.

Although not required as part of the evaluation criteria, data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 16.8 ft/s (5.1 m/s), the highest 0.010-second average ridedown acceleration was -6.6 g and the maximum 0.050-second average acceleration was -3.0 g. In the lateral direction, occupant impact velocity was 9.8 ft/s (3.0 m/s), the highest 0.010-second average ridedown acceleration was -7.6 g and the maximum 0.050-second average lateral acceleration was -4.5 g. These data and other pertinent information from the test are summarized in Figure 51. Vehicular angular displacements are displayed in Figure 52. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 53 through 55.

In summary, the test is judged to be unsatisfactory even though the vehicle was successfully contained and redirected in the initial impact since the vehicle climbed over the rail element in the secondary impact and went behind the barrier. However, the revised end anchorage design (plate welded to the bottom of the end post foundation tube) worked very well. In fact, it appears that the revised end anchorage design is stronger than the current concrete anchor block design used with the sloped anchor since the end post foundation tube was moved only approximately 1-1/2 in. (38 mm) as compared to 7-1/2 in. (191 mm) of movement for the concrete anchor block at the downstream end of the test installation. In any event, the end anchorage performed fine in this test.

The end terminal successfully redirected the vehicle and the vehicle was physically separated from the barrier. However, the rail element came off the paddles and separated from the posts ahead of the vehicle trajectory due to the lateral and longitudinal movement of the rail element. The rail element then dropped to the ground under its own weight after the vehicle disengaged from the rail element. Shortly after the separation, the vehicle turned to the right and impacted the barrier a second time, probably due to damage to the right front wheel. When the vehicle impacted the barrier the second time, the rail element was lying on the ground and the vehicle easily went over the rail element to go behind the barrier. It is believed that this may be a problem inherent in the design of the connection between the rail element and the post of the median barrier and is not necessarily related to the end terminal design. There is also some concern regarding the large lateral deflection





Test No.	472020-9	Impact Speed	61.2 mi/h (98.5 km/h)
Date	03/29/94	Impact Angle	25.4 degrees
		Speed at Parallel	44.4 mi/h (71.4 km/h)
Test Installation	Wyoming Box-Beam End Terminal	Exit Speed	N/A
		Exit Trajectory	N/A
Installation Length	217 ft (66.1 m)	Vehicle Accelerations (Max 50-ms Avg)	
Test Vehicle	1982 Cadillac Coupe	Longitudinal	-3.0 g
		Lateral	-4.5 g
Vehicle Weight		Occ. Impact Velocity	
Test Inertia	4504 lb (2043 kg)	Longitudinal	16.8 ft/s (5.1 m/s)
Gross Static	4504 lb (2043 kg)	Lateral	9.9 ft/s (3.0 m/s)
Vehicle Damage Classification		Occ. Ridedown Acc.	
TAD	01RFQ4	Longitudinal	-6.6 g
CDC	01FREW4	Lateral	-7.6 g
Maximum Vehicle Crush	18.1 in (460 mm)		

Figure 51. Summary of results for test 472020-9.

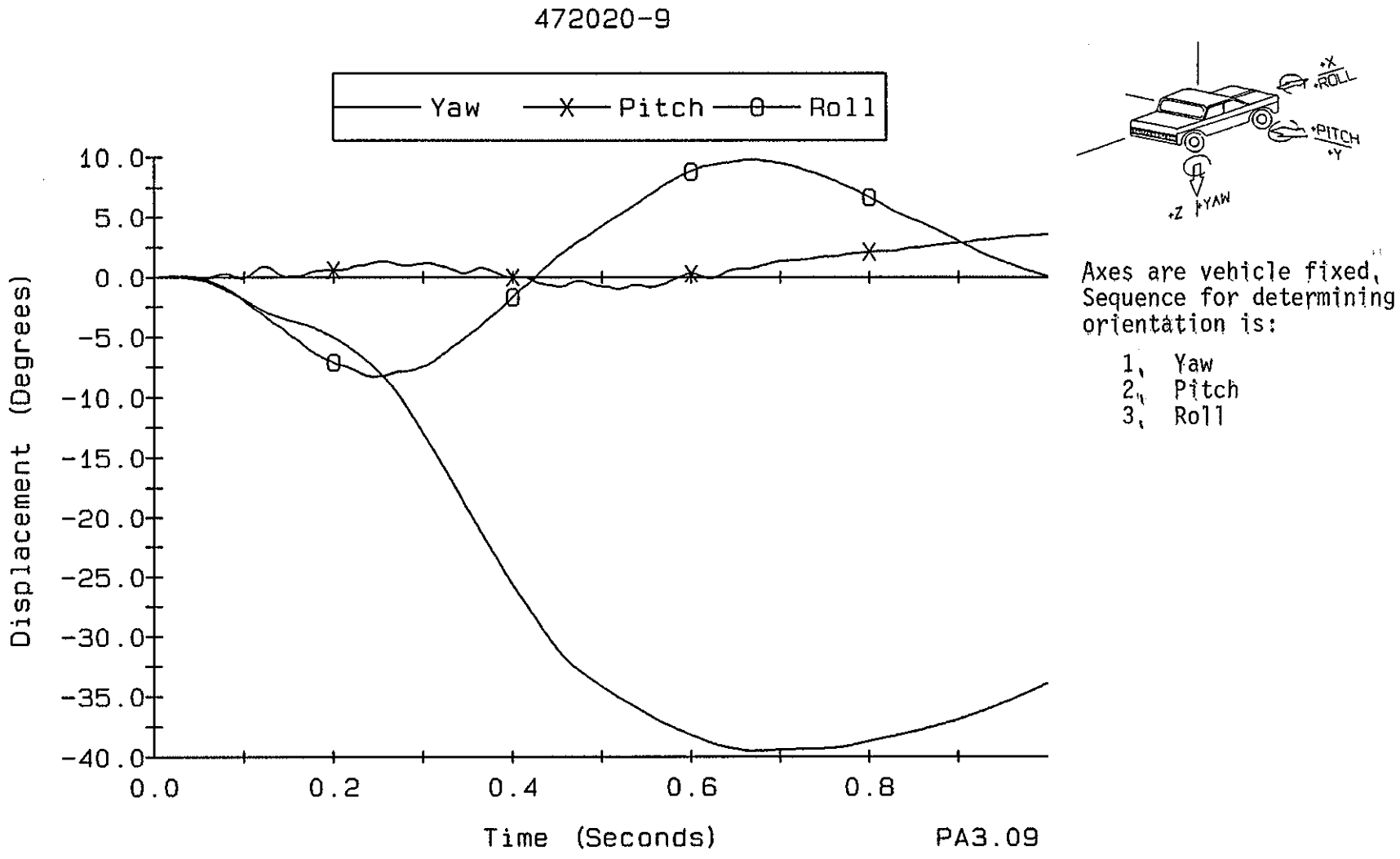


Figure 52. Vehicle angular displacements for test 472020-9.

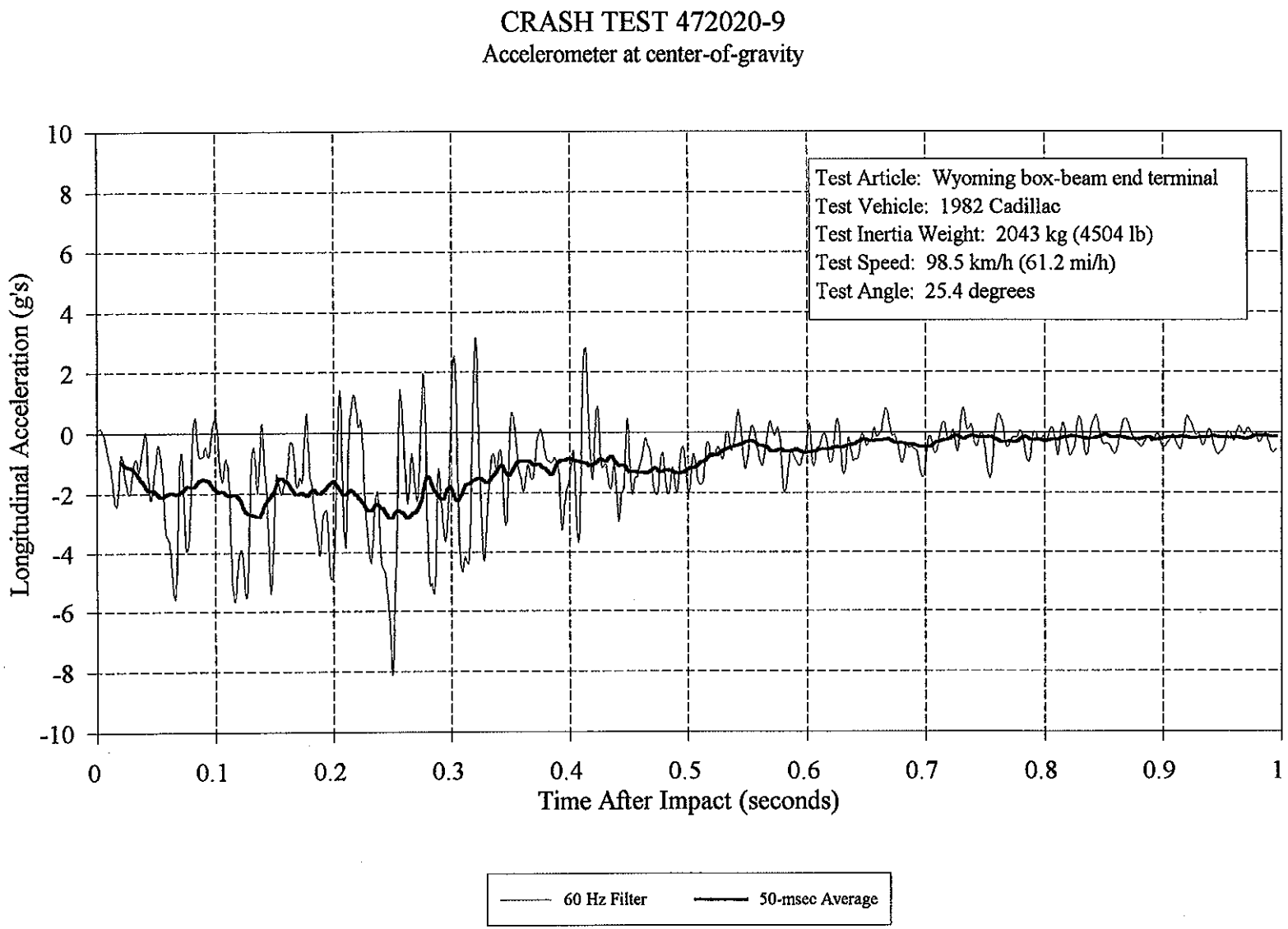


Figure 53. Vehicle longitudinal accelerometer trace for test 472020-9.

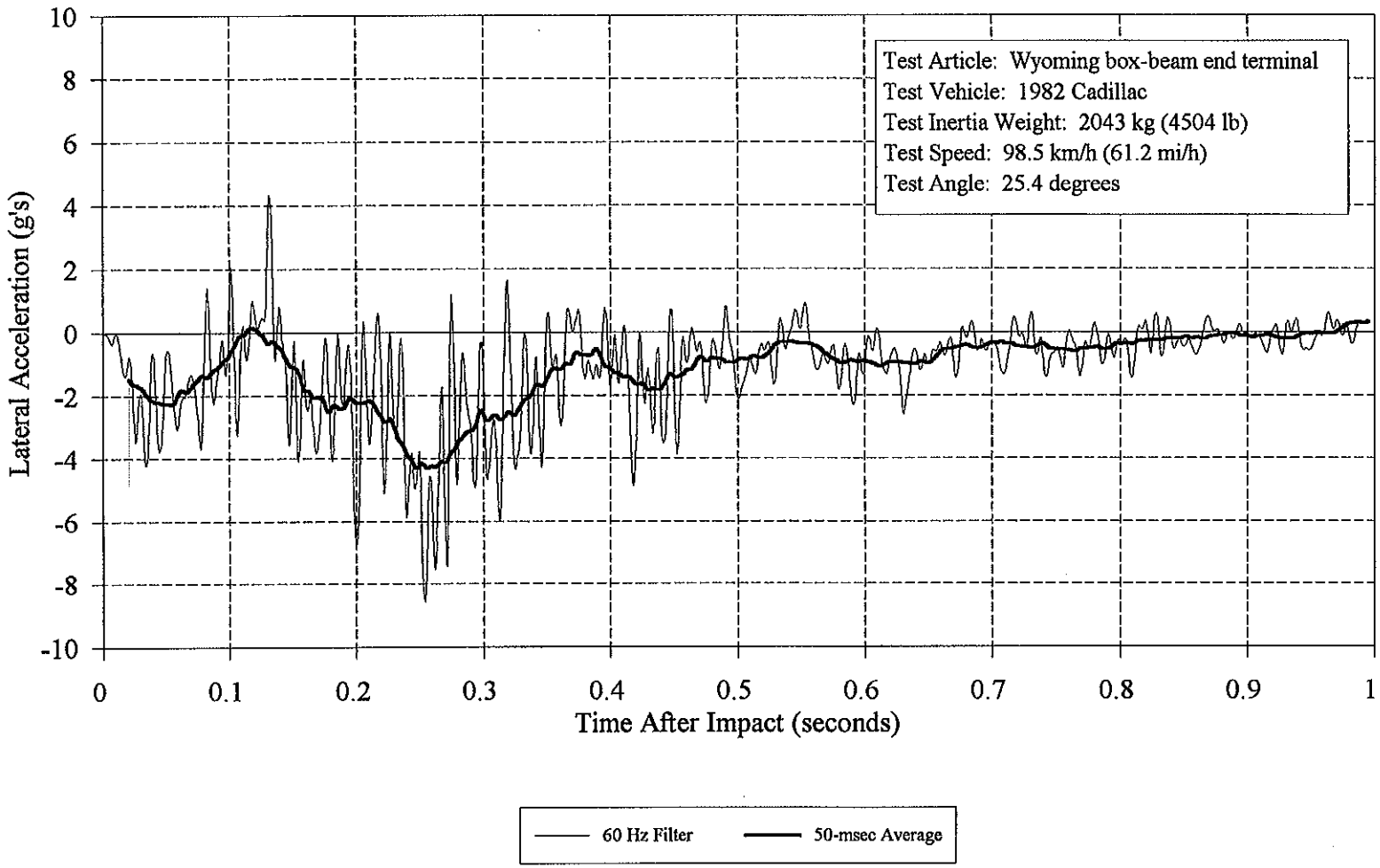


Figure 54. Vehicle lateral accelerometer trace for test 472020-9.

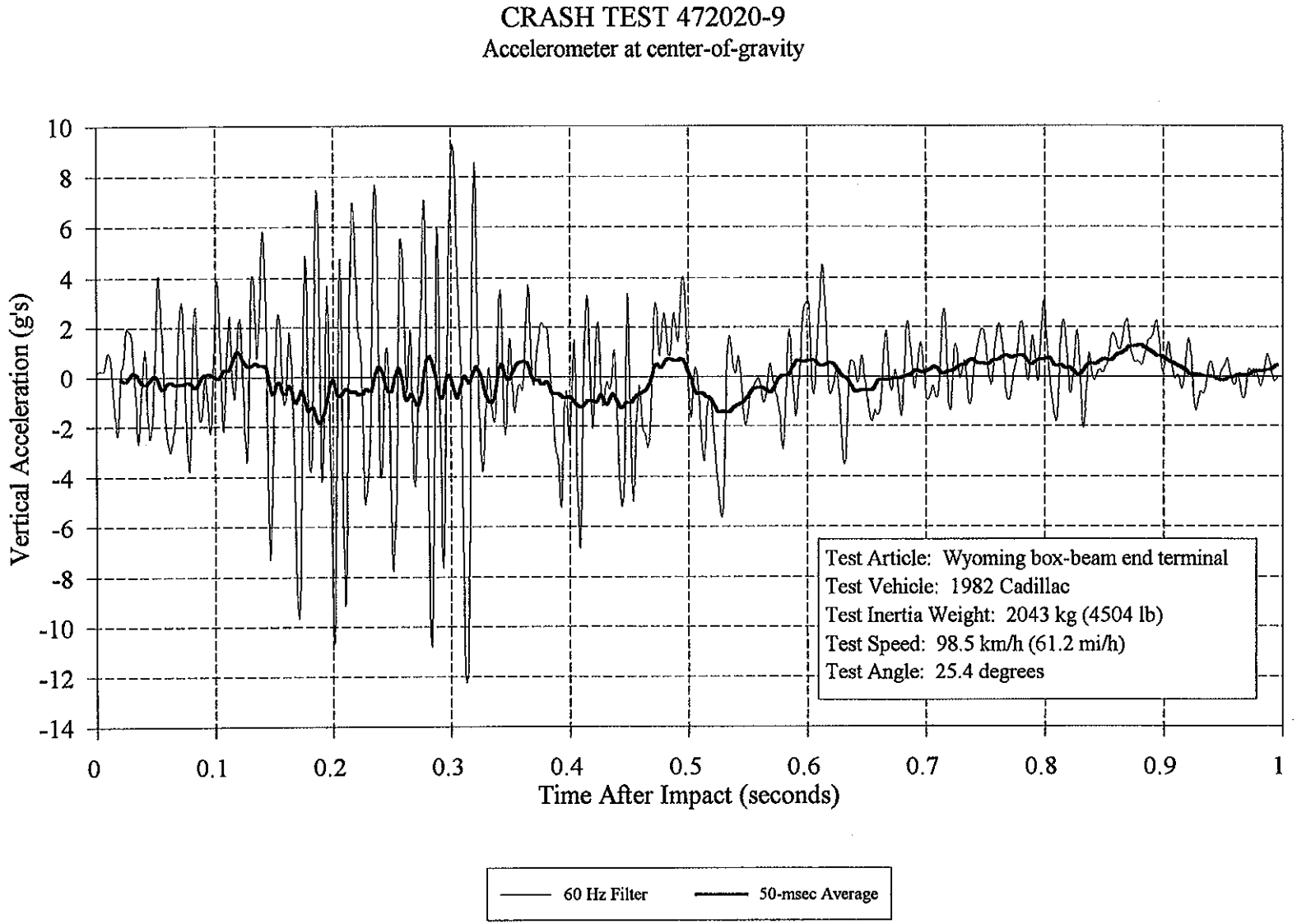


Figure 55. Vehicle vertical accelerometer trace for test 472020-9.

of the end terminal which may have contributed to the problem. Unfortunately, none of the previous crash tests on the box-beam median barrier could be used for comparison purposes since they were not conducted in accordance with NCHRP Report 230 test conditions, i.e., a 4,500-lb (2,043-kg) passenger car impacting the barrier at a nominal speed and angle of 60 mi/h (96.6 km/h) and 25 degrees. Also, there are other differences, e.g., barrier height, connection details, etc., in the test installations that render the comparisons with the previous crash tests very difficult.

The problem with the connection design could be corrected by using of a more positive connection between the rail element and the posts, such as a post angle and through bolt connection, for the first several sections of the 6 in. x 8 in. (152 mm x 203 mm) median barrier beyond the end terminal. The positive connection would keep the rail element from disengaging from the posts ahead of the vehicle trajectory. Two options for the design of this connection were considered, as follows:

1. The posts will remain centered beneath the rail element. A post angle and through bolt connection will be used instead of the paddle and slot configuration. The connection design will consist of a post angle with one leg of the angle bolted to the post and the other leg resting against the bottom of the 6 in. x 8 in. (152 mm x 203 mm) box-beam rail element and through bolted to the rail element.
2. The posts will be placed alternately on either side of the medial barrier rail element using connections similar to those used with the guardrail. The connection consists of a post angle bolted to the post on one leg of the angle and the rail element is attached to the other leg of the shelf angle using through bolts.

The first alternative provides a cleaner design and requires the least modification to the existing design. It provides positive connection and additional lateral stiffness to the median barrier section, but not to the end terminal section. The second alternative provides a slightly higher lateral stiffness since the lateral movement of the rail element will be resisted by not only the through bolts, but also the bending of every other post. However, this increase in lateral stiffness for the median barrier section is likely to be minimal since the connecting bolts are selected to have similar strength as that of bending the posts. On the negative side, this design option will likely create more problems with initial installation and subsequent maintenance since the posts are offset alternately. The embedment length of the median barrier posts will be 3 in. (76 mm) less than that of the guardrail

posts since the median barrier is 30 in. (0.76 m) high compared to 27 in. (0.69 m) for the guardrail. The esthetics of offsetting the posts alternately is another factor for consideration.

After consulting with the Department, the first design alternative was selected for the next test. The connection design, as previously shown in Detail MB-9 of Figure 1, consists of an 8 in. x 4 in. (203 mm x 102 mm) post angle fabricated from a 3/8-in. (9.5 mm) thick bent plate, and is 2 in. (51 mm) in length. The post angle is bolted to the post on the long leg of the angle using two 3/4-in. (19.1-mm) diameter, 1-1/2 in. (38.1 mm) long A307 bolts. The short leg of the angle rests against the bottom of the 6 in. x 8 in. (152 mm x 203 mm) box-beam rail element and a 1/2 in. (12.7 mm) wide by 2 in. (51 mm) long slot is provided for bolting the rail element to the post angle with a 7/16-in. (11.1-mm) diameter, 7-1/2 in. (191 mm) long A307 bolt.

Two different bolt diameters were considered: 3/8-in. (9.5-mm) or 7/16-in. (11.1-mm). The choice of the bolt diameter was based on the consideration that the force required to shear the bolt should be comparable to that required to yield the post. This would make full use of the post strength while still allowing the post to separate from the rail element, thus minimizing the potential of reducing the effective height of the rail element due to excessive bending of the posts. Analysis indicated that a 3/8-in. diameter, A307 bolt should be adequate, but the larger 7/16-in. (11.1-mm) diameter bolt was selected for a more conservative design.

4.5 Repeat of Large Car Length-of-Need Strength Test (Test No. 472020-10)

The test installation was repaired and reconstructed with the post angle and through bolt connection for the median barrier length-of-need section and the large car length-of-need test was repeated. Note that the post angle and through bolt connection design was used for the entire 144 ft (43.9 m) of median barrier length-of-need in the test installation since it was unsure how many posts or sections of rail element will be required. Photographs of the test installation are shown in Figure 56.

A 1981 Lincoln Continental (shown in Figures 57 and 58) was used for the test. The test inertia mass and gross static mass of the vehicle were both 4,500 lb (2,043 kg). The heights to the upper and lower edges of the vehicle bumper were 20.9 in. (530 mm) and 11.4 in. (290 mm), respectively. Other dimensions and information on the vehicle are given in Figure 59. The vehicle was directed into the test installation using a cable reverse tow and guidance system and was free wheeling and unrestrained just prior to impact.

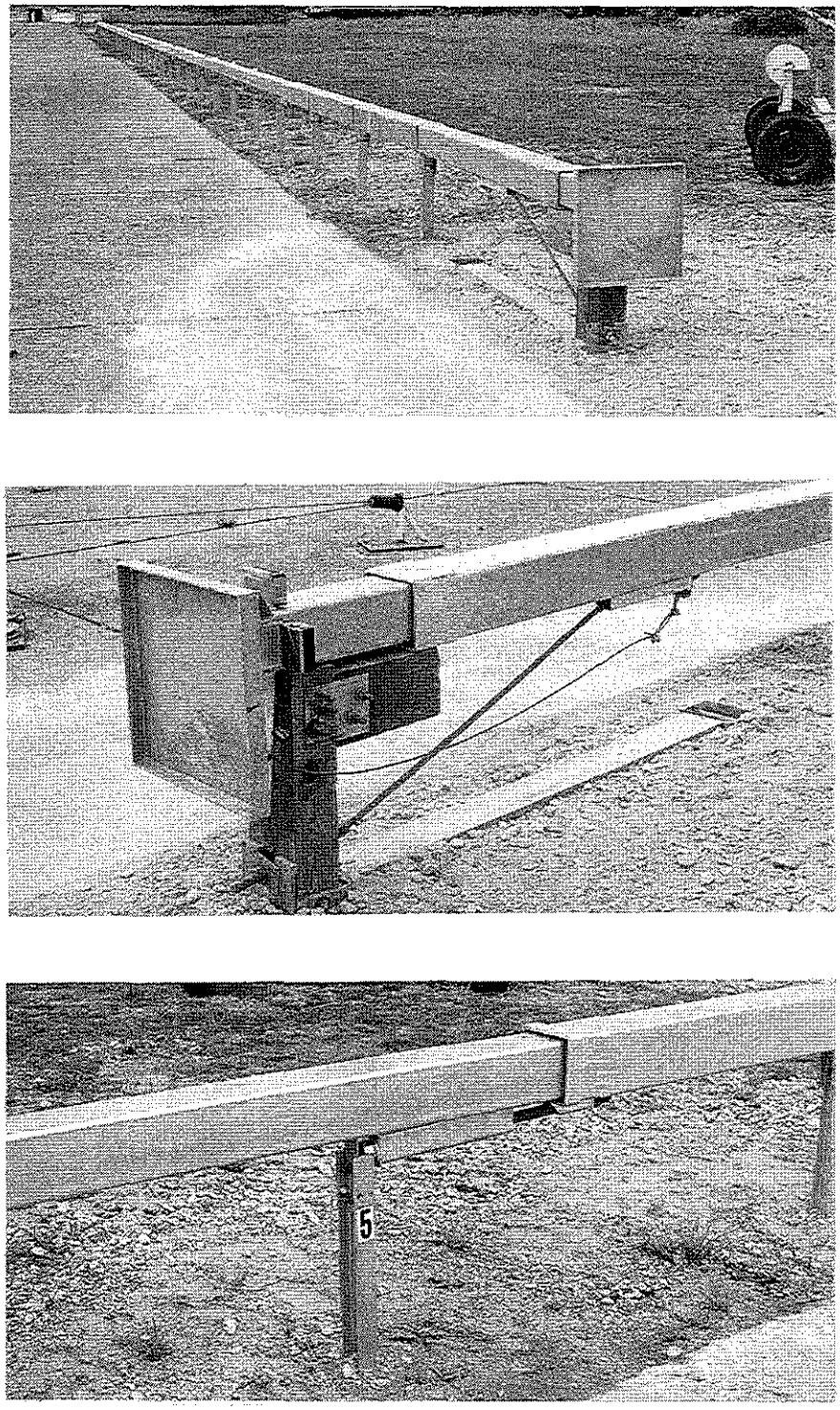


Figure 56. Wyoming box-beam rail installation before test 472020-10.

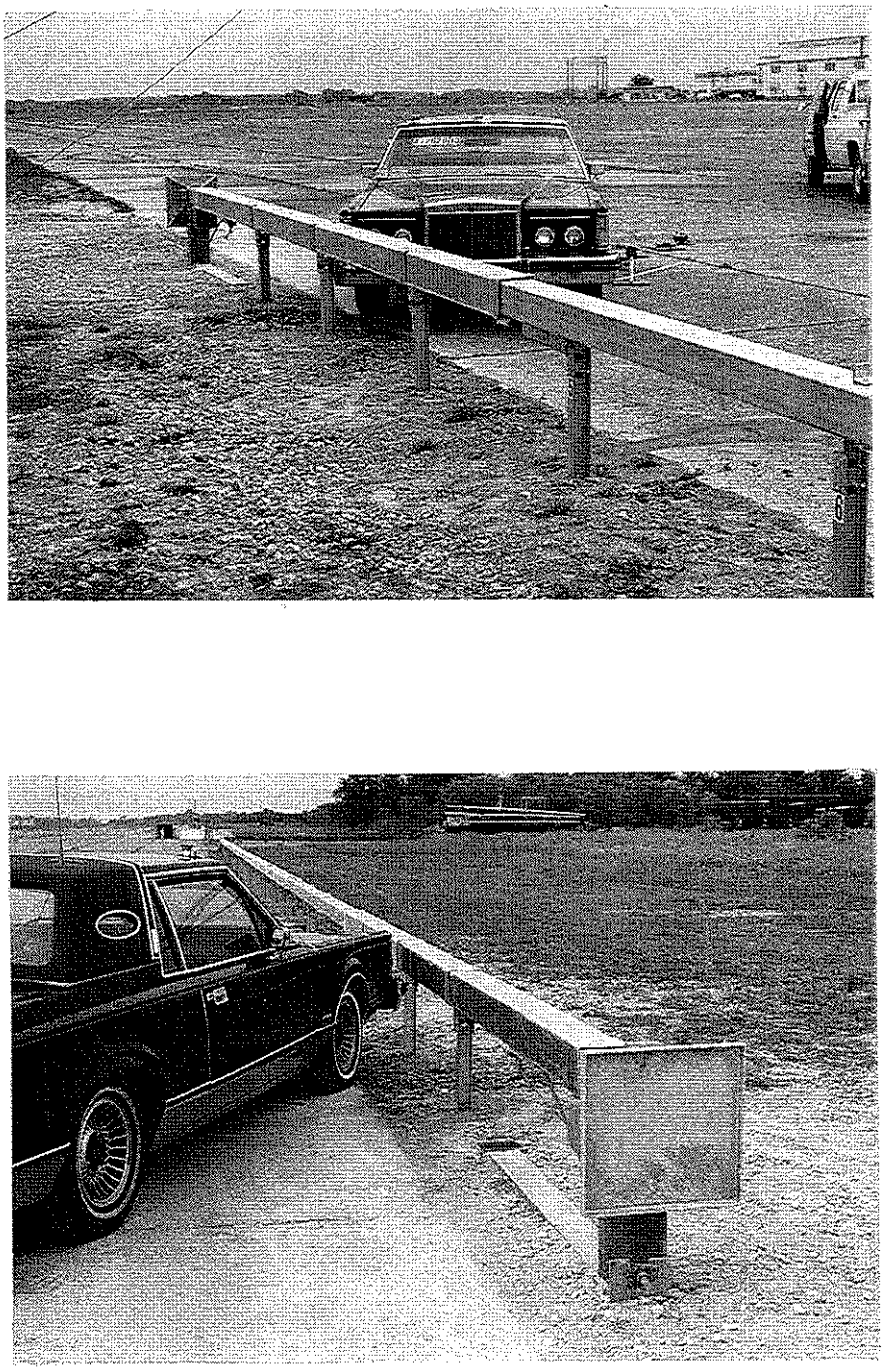


Figure 57. Vehicle/rail geometrics for test 472020-10.

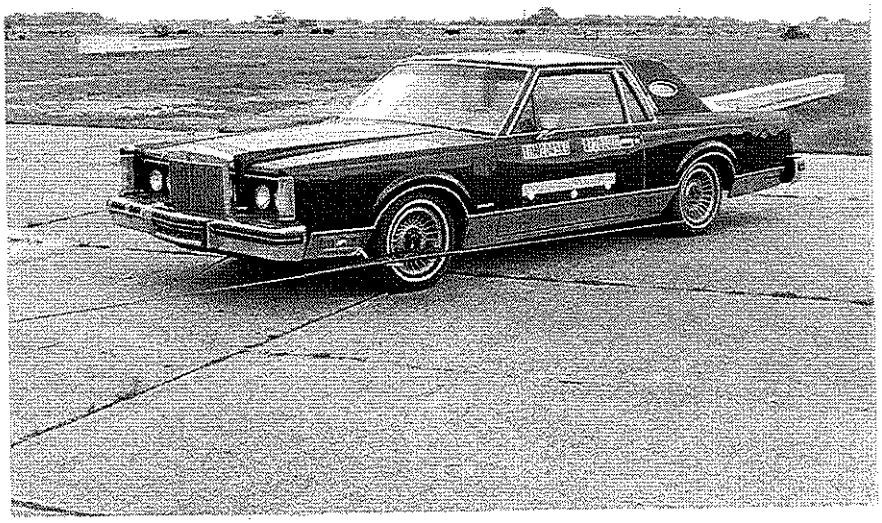


Figure 58. Vehicle before test 472020-10.

DATE: 5-11-94 TEST NO.: 472020-10 VIN NO.: 1MRBP95F2BY665327 MAKE: Lincoln

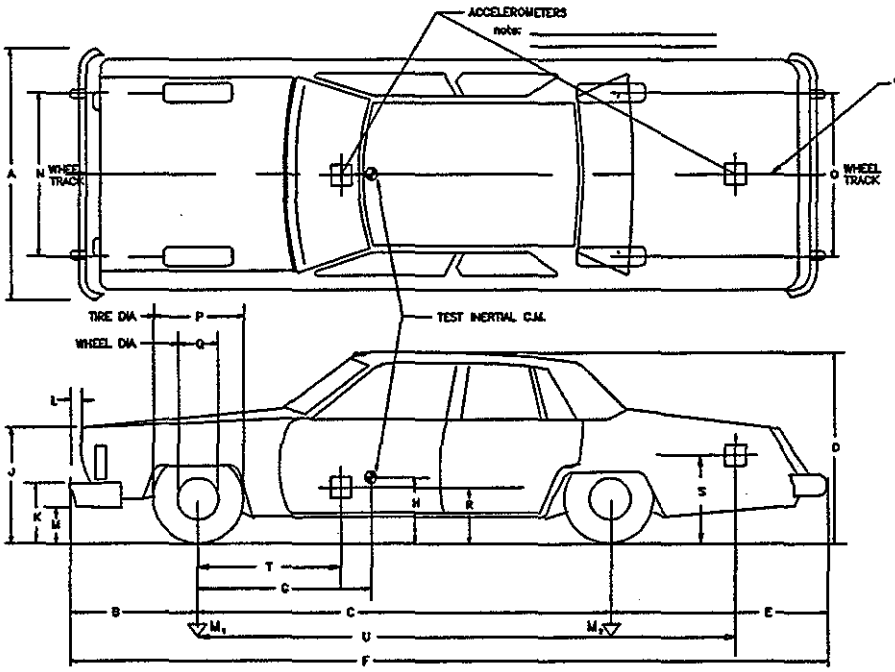
MODEL: Continental YEAR: 1981 ODOMETER: 17066 TIRE SIZE: P205 75R15

TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF 567 RF 535 LR 470 RR 471

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

Dent in right rear quarter-panel above right rear tire (marked).



ENGINE TYPE: 8 cyl gas

ENGINE CID: 5.0 liter

TRANSMISSION TYPE:

X AUTO

__ MANUAL

OPTIONAL EQUIPMENT:

_____

_____

_____

DUMMY DATA:

TYPE: _____

MASS: _____

SEAT POSITION: _____

1 mm = 0.039 in
1 kg = 2.202 lb

GEOMETRY – (mm)

A	1920	E	1400	J	905	N	1590	R	460
B	1140	F	5444	K	540	O	1580	S	760
C	2904	G	1337	L	130	P	670	T	1305
D	1405	H		M	290	Q	415	U	3924

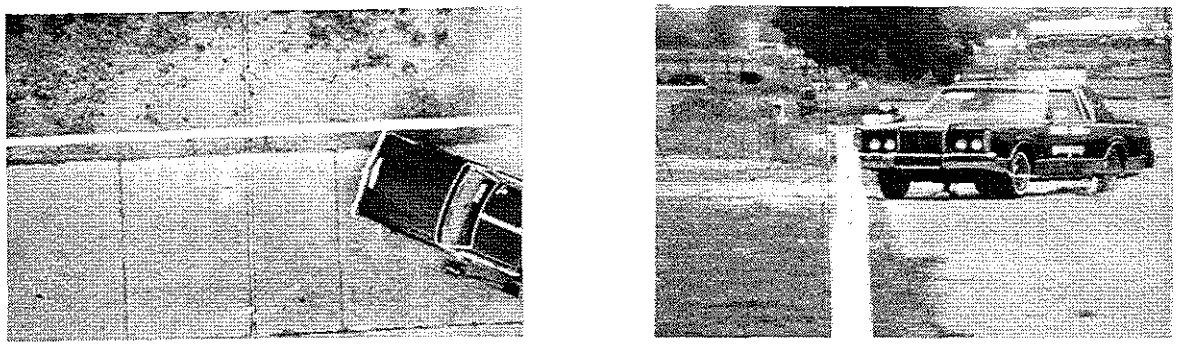
MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M_1	1059	1102	
M_2	762	941	
M_T	1821	2043	

Figure 59. Vehicle properties for test 472020-10.

The vehicle impacted the box-beam median barrier terminal installation at the beginning of the length of need, i.e., post 3 or 16 ft-2 in. (4.9 m) downstream from the nose, at a speed of 60.3 mi/h (97.0 km/h) and at an angle of 25.3 degrees. Shortly after impact, the bumper of the vehicle contacted post 3 and pushed the post to the right. As the box-beam deformed, post 3 was pulled back to the left and post 4 began to displace. At 0.064 second after impact, the vehicle contacted post 4 and post 6 began to displace with post 7 and 8 following. Redirection of the vehicle began at 0.076 second and the vehicle contacted post 5 at 0.126 second. At 0.207 second, the vehicle contacted post 6, post 9 began to displace, and the box-beam rail element began to drop. The vehicle contacted post 7 at 0.291 second, and the rear of the vehicle impacted the rail at 0.340 second. The vehicle was parallel with the rail at 0.375 second, travelling at 44.4 mi/h (71.4 km/h). At 0.385 second, the vehicle contacted post 8 and the tire aired out as it rode over the post. The box-beam rail element continued to drop to the ground as the vehicle continued to be redirected and the box-beam deformed. At 0.430 second, the wooden end post was fractured at ground level. The box-beam rail element contacted the ground at 0.500 second. The vehicle lost contact with the box-beam rail element at 0.912 second, and the vehicle exited the installation travelling at an angle of 14.4 degrees. Maximum dynamic displacement of the rail of 11.7 ft (3.6 m) occurred at 1.076 seconds. Brakes on the vehicle were applied 4.5 seconds after impact, and the vehicle subsequently came to rest 206 ft (63 m) down and 56 ft (17 m) forward of the point of impact. Sequential photographs of the test are shown in Figures 60 and 61.

The end post was broken off at ground level and the rail was separated from the first eleven posts. The rail was still attached to the remaining posts; however, the post angles on posts 12, 13, and 14 were bent. Posts 2 through 11 were displaced laterally, with a maximum rearward post displacement at post 10 of 14 in. (356 mm). Maximum permanent deformation of the rail was 11.2 ft (3.4 m). The upstream foundation tube for the wooden end post was displaced 2 in. (51 mm) and the downstream end anchor was moved 0.75 in. (19 mm). The vehicle was in contact with the rail for a total length of 51.7 ft (15.7 m). Damage sustained to the rail installation during testing is shown in Figure 62.

The vehicle received moderate damage, as shown in Figure 63. The damage sustained was concentrated mostly at the right front quarter with minor damage to the right rear quarter of the vehicle where the rear slapped the rail. Maximum crush was 9.8 in. (250 mm) at the right front corner the vehicle. In addition, the left front corner of the vehicle was shifted 1.2 in. (30 mm) to the



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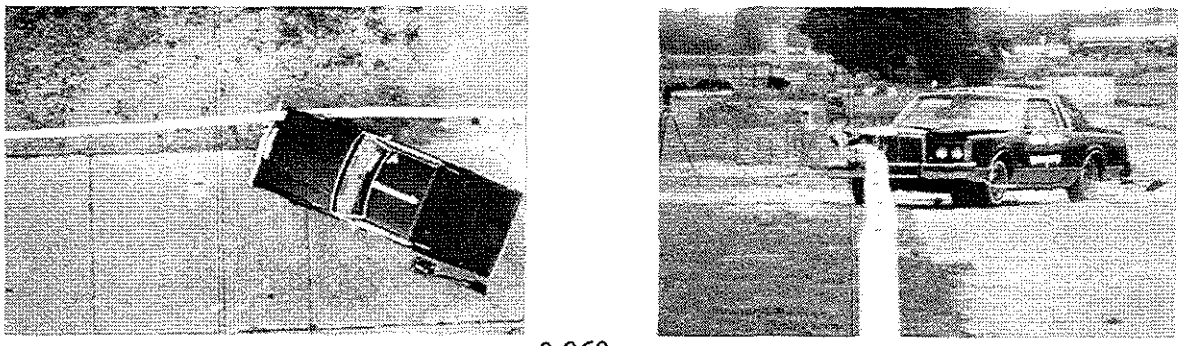

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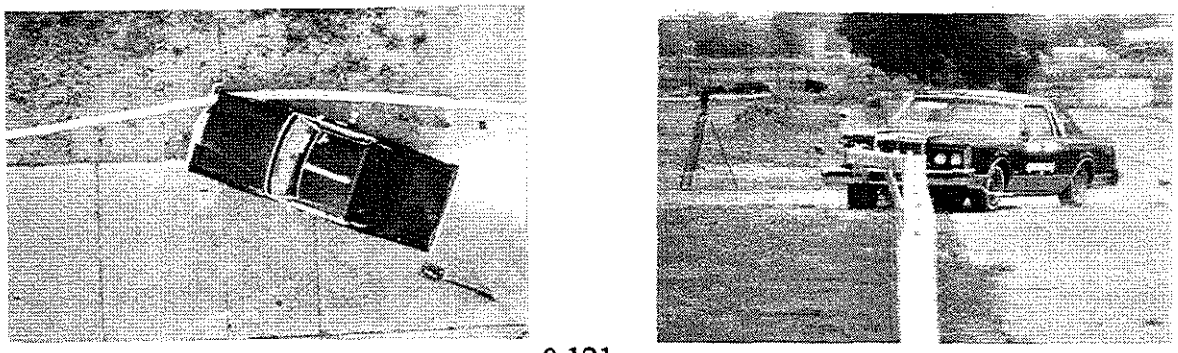
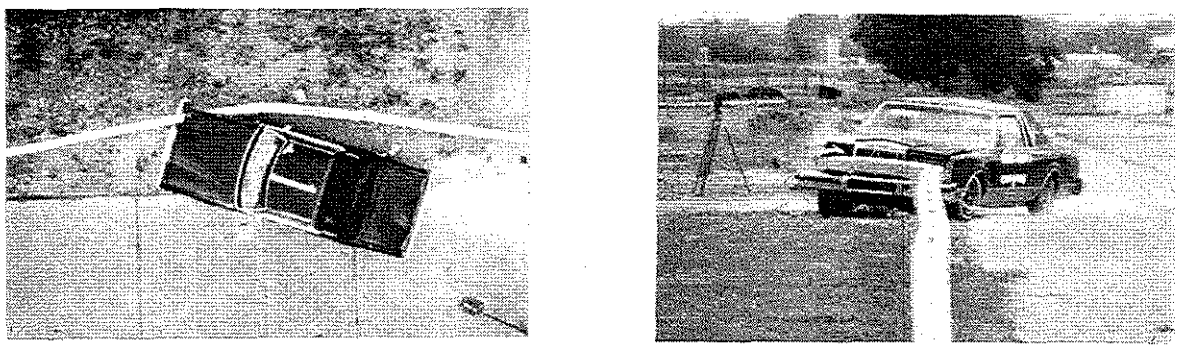
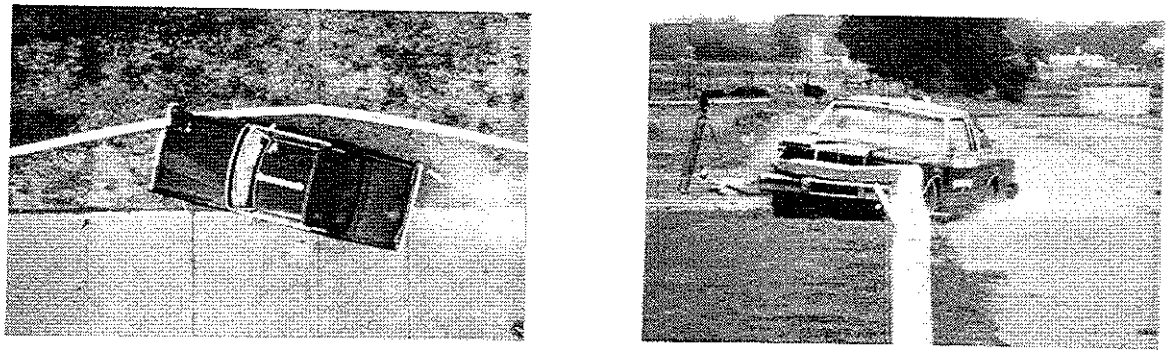


0.121 s

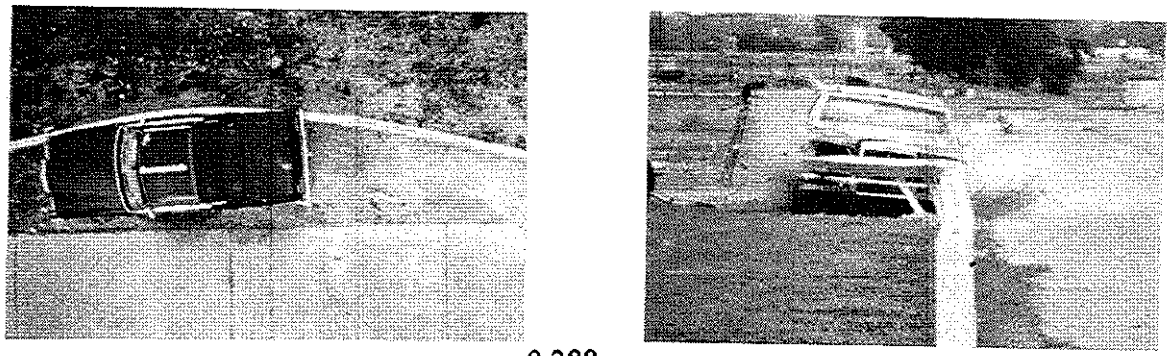


0.181 s

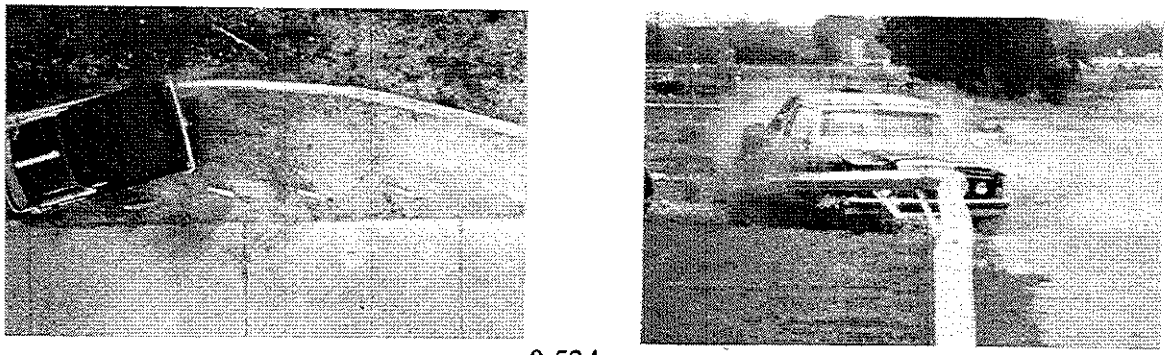
Figure 60. Sequential photographs for test 472020-10.
(overhead and frontal views)



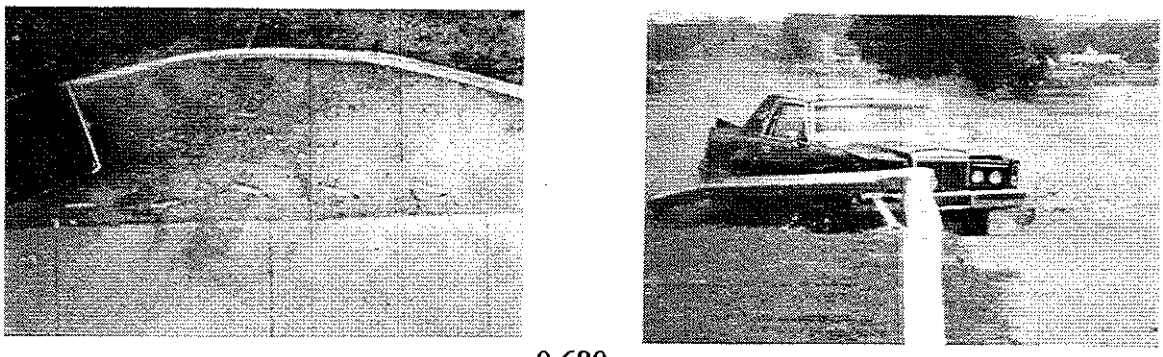
0.242 s



0.388 s

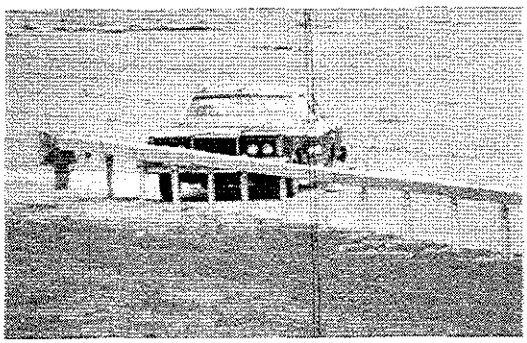


0.534 s

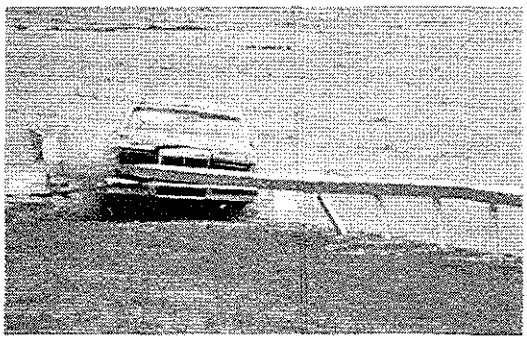


0.680 s

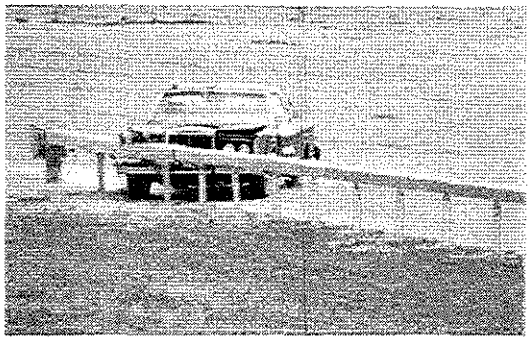
Figure 60. Sequential photographs for test 472020-10 (continued).
(overhead and frontal views)



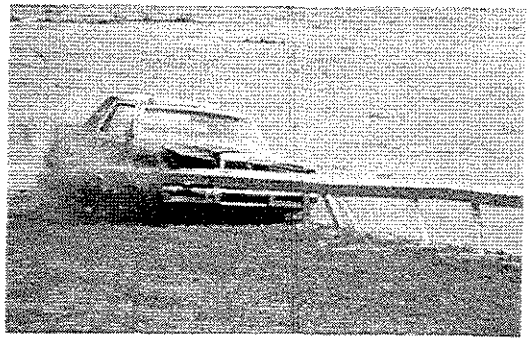
0.000 s



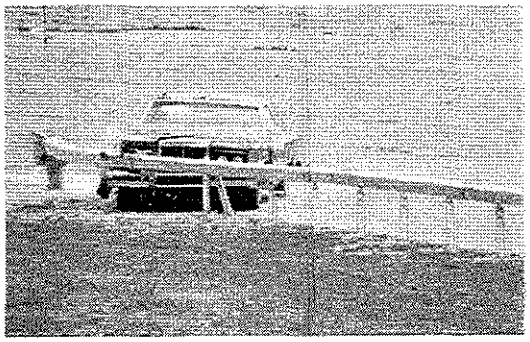
0.242 s



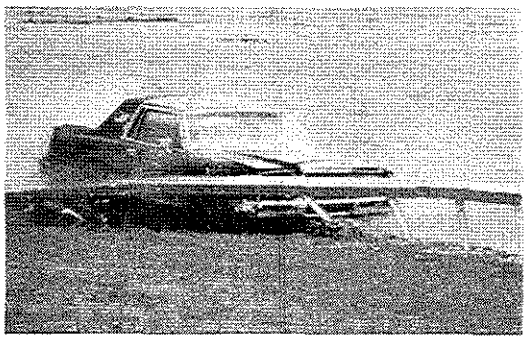
0.060 s



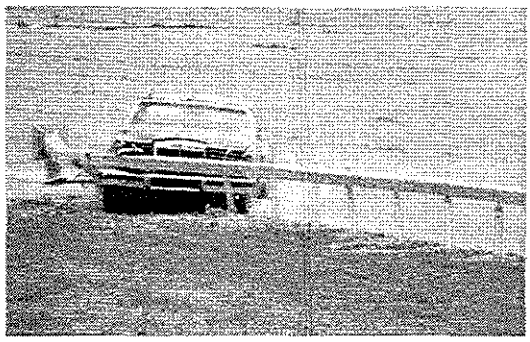
0.388 s



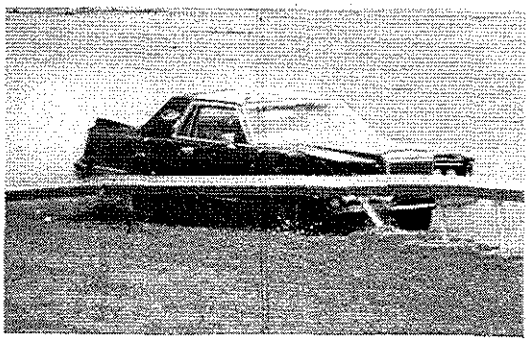
0.121 s



0.534 s

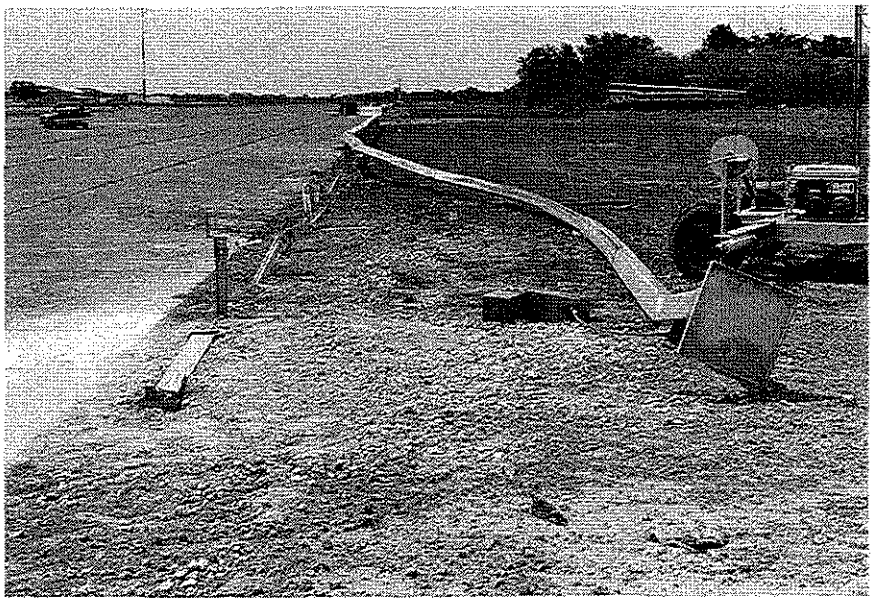


0.181 s



0.680 s

Figure 61. Sequential photographs for test 472020-10.
(behind the rail view)



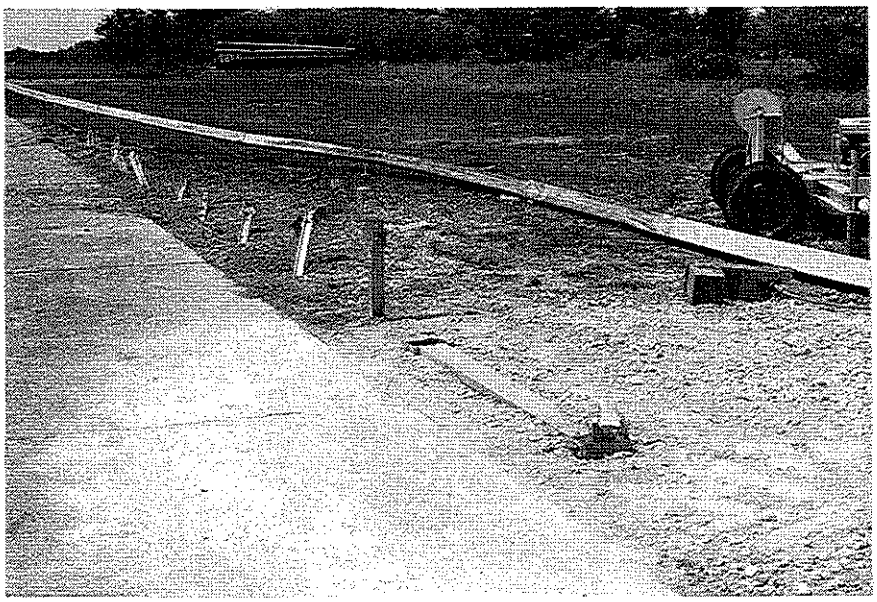


Figure 62. Wyoming box-beam rail installation after test 472020-10.

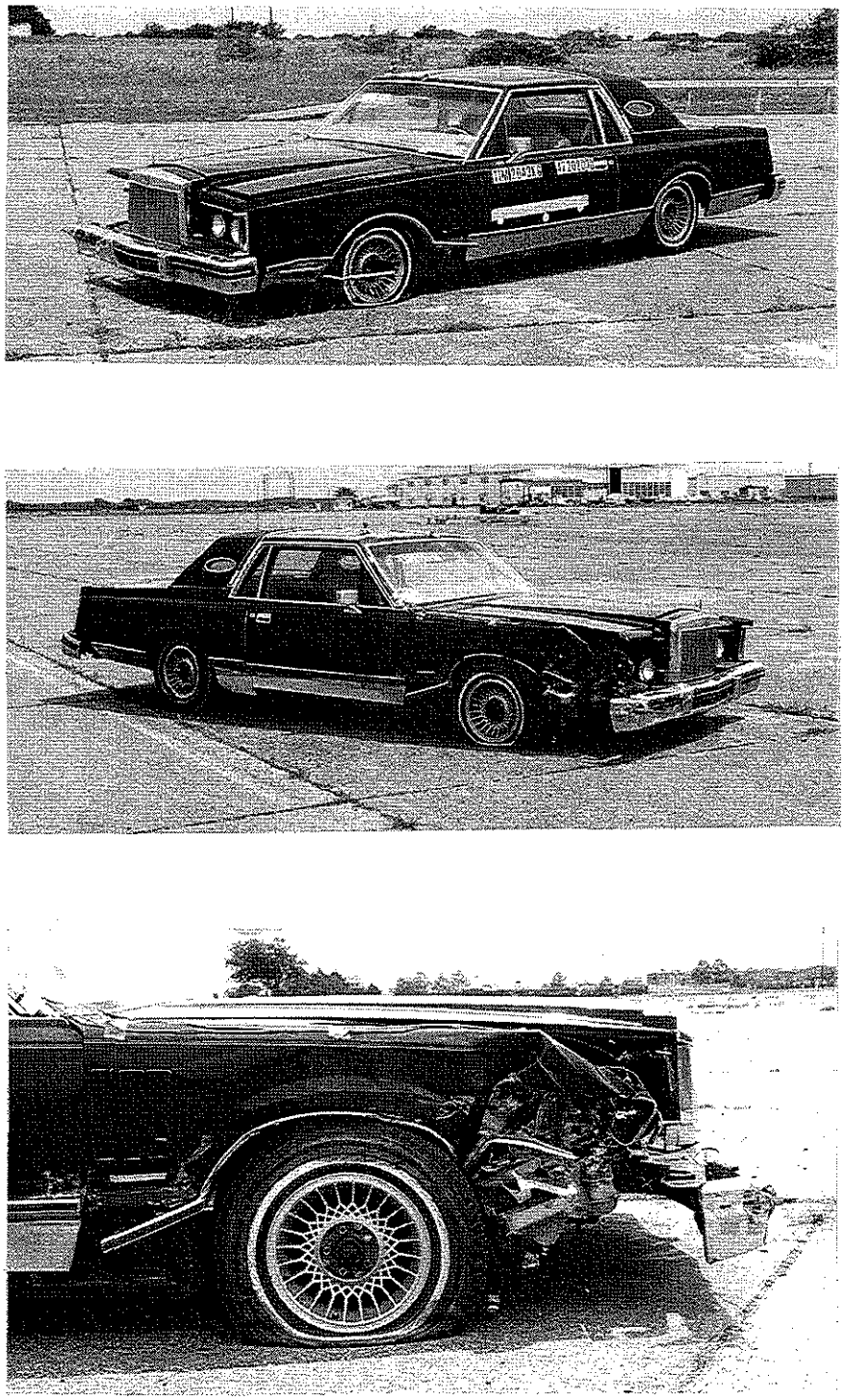


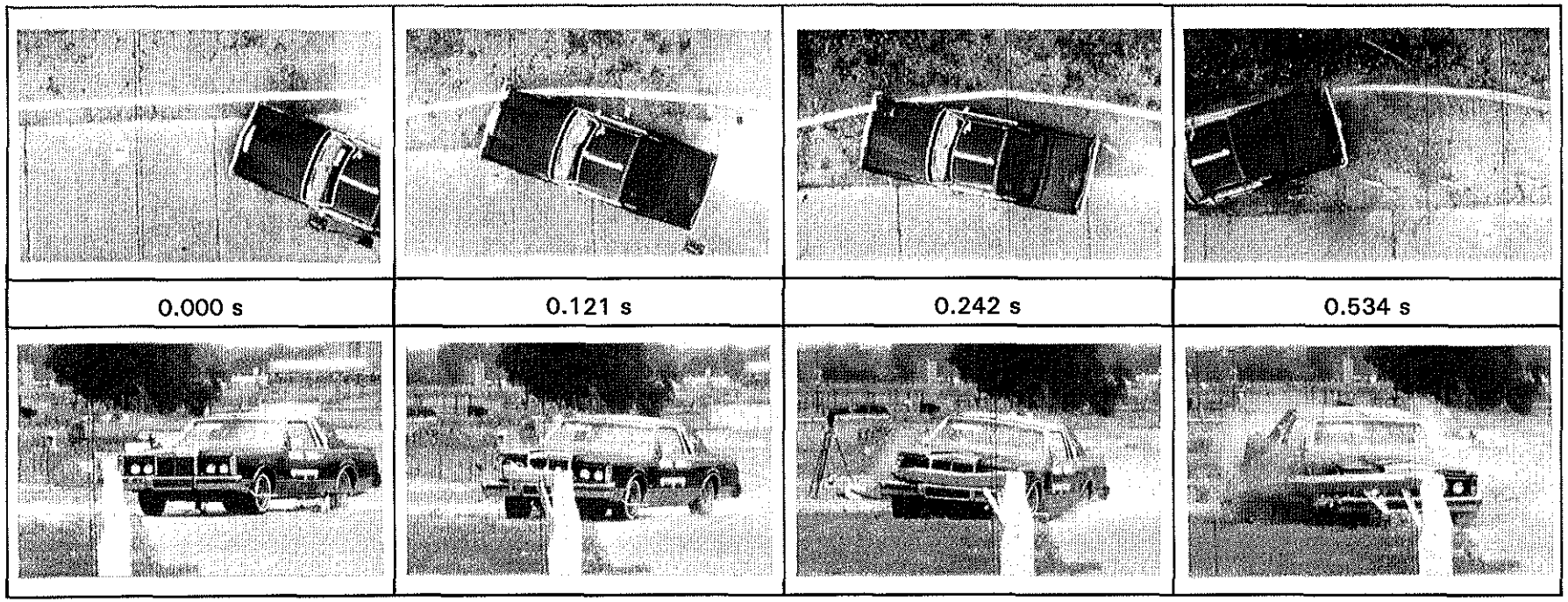
Figure 63. Vehicle after test 472020-10.

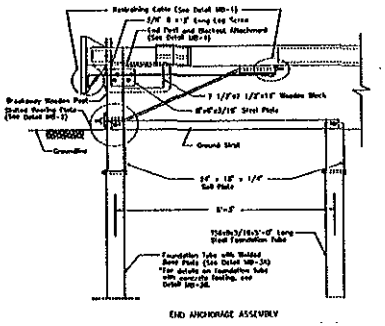
left. There was no deformation of the occupant compartment. Both front tires and rims were damaged due to contact with the metal posts.

Although not required as part of the evaluation criteria, data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of the occupant risk factor and were computed as follows. In the longitudinal direction, occupant impact velocity was 16.4 ft/s (5.0 m/s), the highest 0.010-second average ridedown acceleration was -5.6 g and the maximum 0.050-second average acceleration was -2.9 g. In the lateral direction, occupant impact velocity was 10.2 ft/s (3.1 m/s), the highest 0.010-second average ridedown acceleration was -9.1 g and the maximum 0.050-second average lateral acceleration was -3.9 g. These data and other pertinent information from the test are summarized in Figure 64. Vehicular angular displacements are displayed in Figure 65. Vehicle accelerations versus time filtered at SAE J211 (Class 180) are presented in Figures 66 through 68.

In summary, the barrier is judged to have performed satisfactorily in this length-of-need strength test. The vehicle was contained and redirected by the terminal. The wooden end post broke off as the rail element was dropping to the ground. As the rail element dropped to the ground under its own weight, the angle of the anchor cable with the ground was reduced. This effectively increased the longitudinal component of the load being transferred by the cable, which eventually led to the shearing of the wooden end post at ground level. It should be noted that the breaking of the wooden end post occurred after the vehicle was substantially redirected and was in the process of exiting the installation. There were no debris or detached elements from the end terminal or the vehicle that would pose any potential hazard to adjacent traffic. The test installation received severe damage and the impacting vehicle sustained moderate damage. The vehicle was stable during and after the impact sequence. The exit angle of 14.4 degrees was less than 60 percent of the impact angle and the post-impact trajectory of the vehicle is not considered to have posed any hazard to adjacent traffic. Although not required as part of the evaluation criteria, the occupant risk factors are all well within the design limits set forth in NCHRP Report 230.

As discussed previously, there was some debate as to whether a 3/8-in. (9.5-mm) or a 7/16-in. (11.1-mm) diameter A307 bolt should be used for the connection and the 7/16-in. (11.1-mm) diameter bolt was selected to provide a more conservative design. Based on results of the test, it appears that the 7/16-in. (11.1-mm) diameter bolt is stronger than needed and a 3/8-in. (9.5-mm) diameter A307 bolt would have been adequate.





Test No.	472020-10	Impact Speed	60.5 mi/h (97.3 km/h)
Date	05/11/94	Impact Angle	25.3 deg
		Speed at Parallel	44.4 mi/h (71.4 km/h)
Test Installation	Wyoming Box-Beam End Terminal	Exit Speed	Not available
		Exit Trajectory	14.4 deg
Installation Length	217 ft (66.1 m)	Vehicle Accelerations (Max 50-ms Avg)	
Test Vehicle	1981 Lincoln Continental	Longitudinal	-2.9 g
Vehicle Weight		Lateral	-3.9 g
Test Inertia	4500 lb (2043 kg)	Occ. Impact Velocity	
Gross Static	4500 lb (2043 kg)	Longitudinal	16.4 ft/s (5.0 m/s)
Vehicle Damage Classification		Lateral	10.2 ft/s (3.1 m/s)
TAD	01RFQ3 & 01RD2	Occ. Ridedown Acc.	
CDC	01FREK3 & 01RDEW2	Longitudinal	-5.6 g
Maximum Vehicle Crush	9.8 in (250 mm)	Lateral	-9.1 g

Figure 64. Summary of results for test 472020-10.

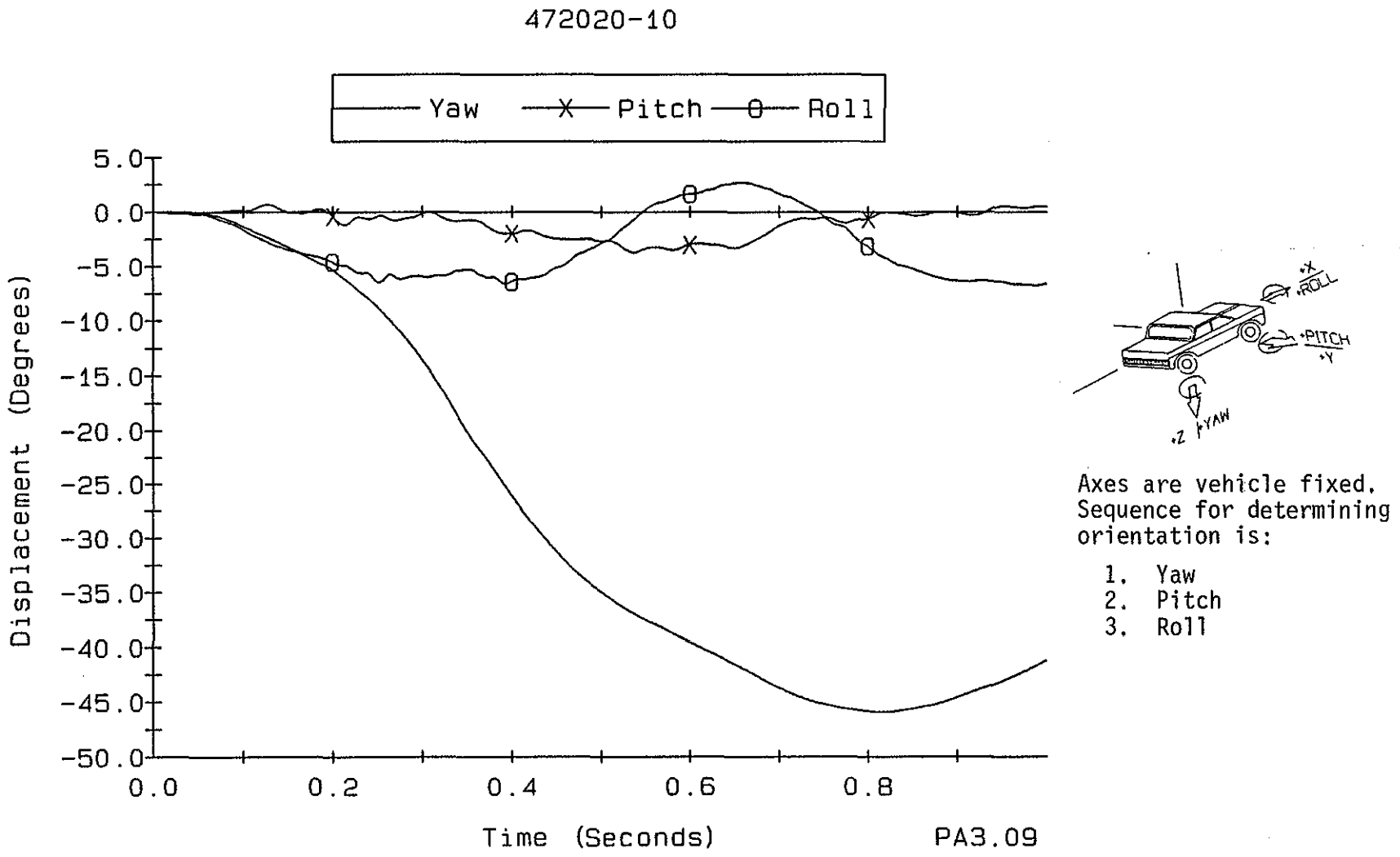


Figure 65. Vehicle angular displacements for test 472020-10.

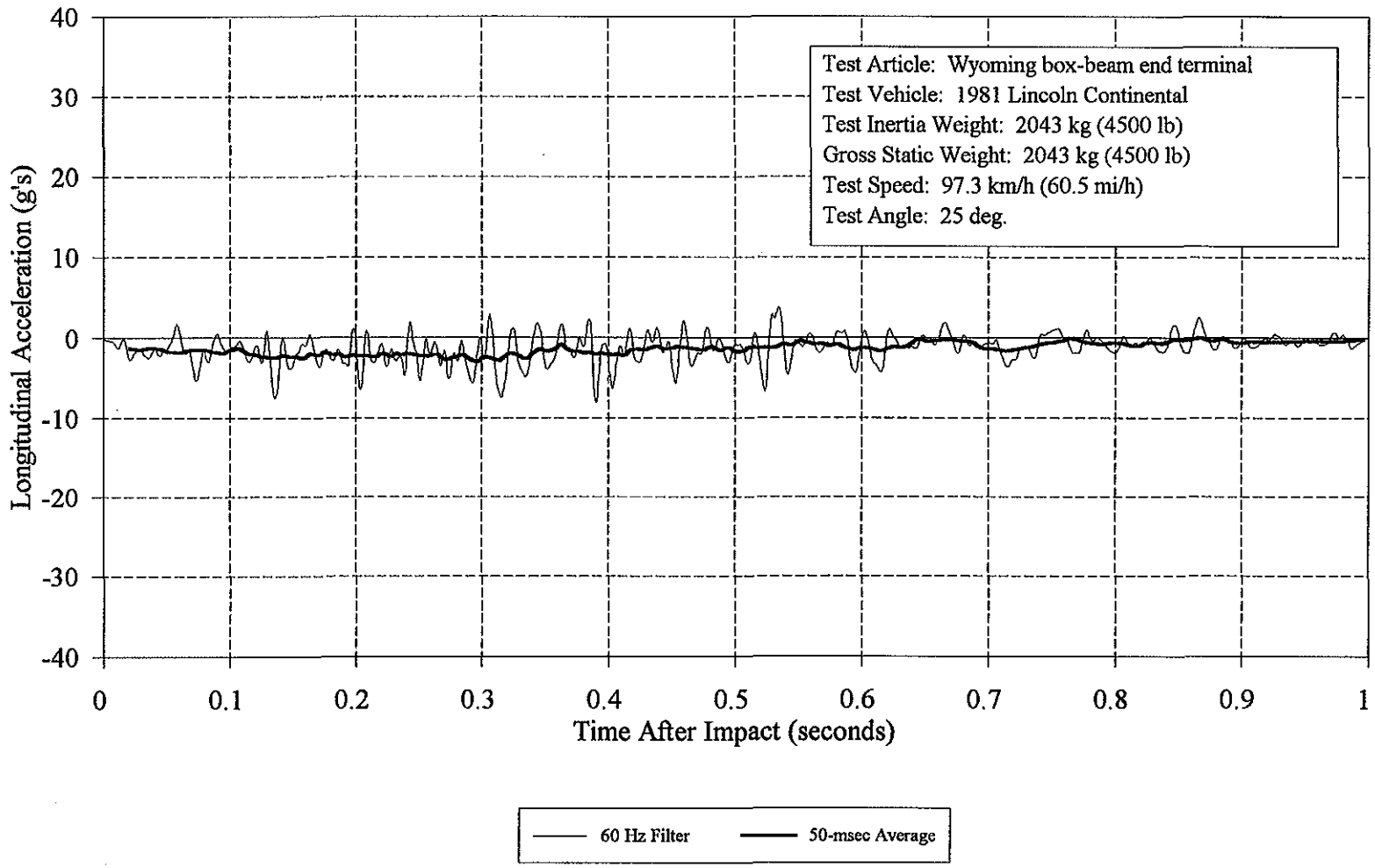


Figure 66. Vehicle longitudinal accelerometer trace for test 472020-10.

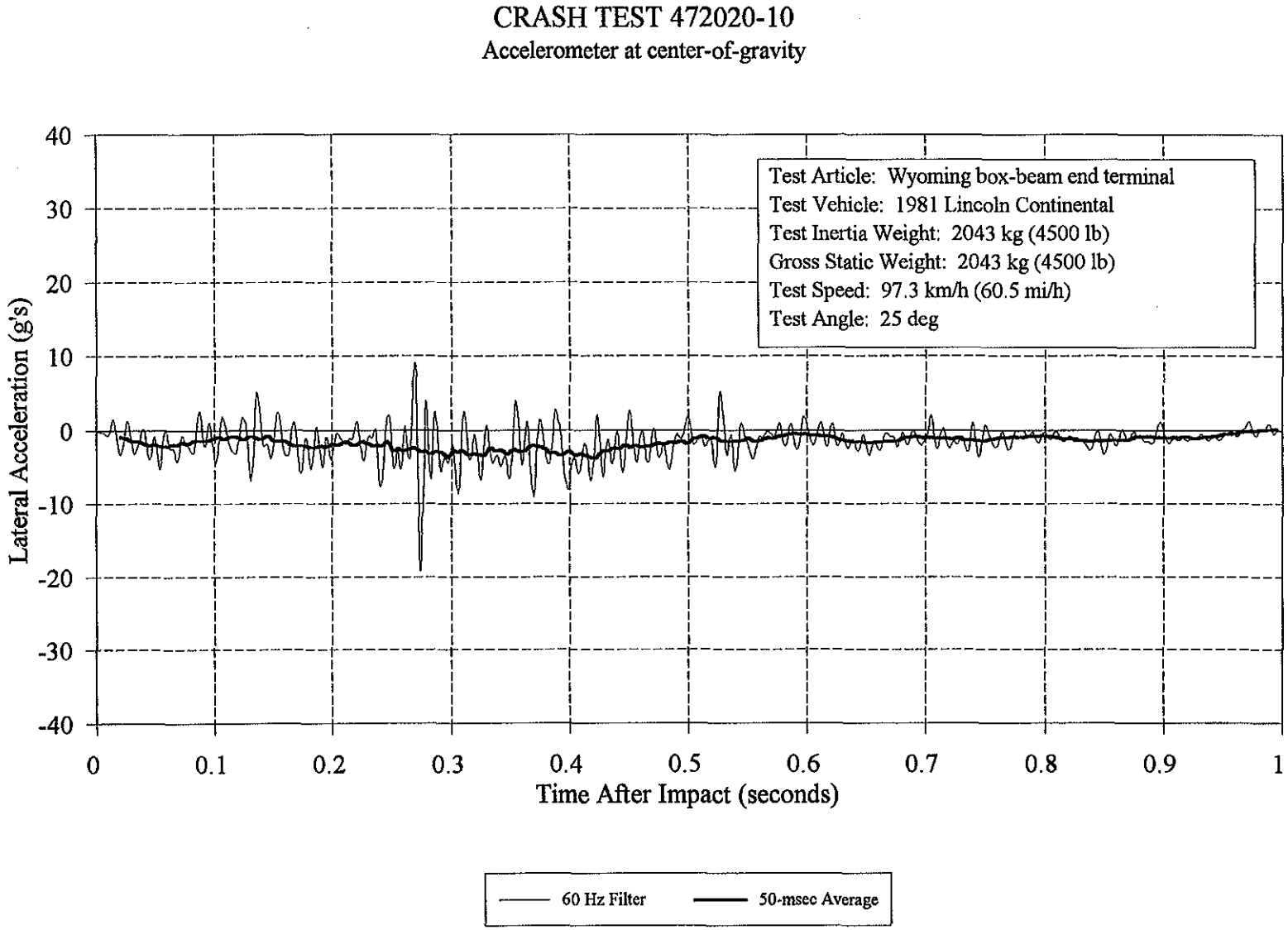


Figure 67. Vehicle lateral accelerometer trace for test 472020-10.

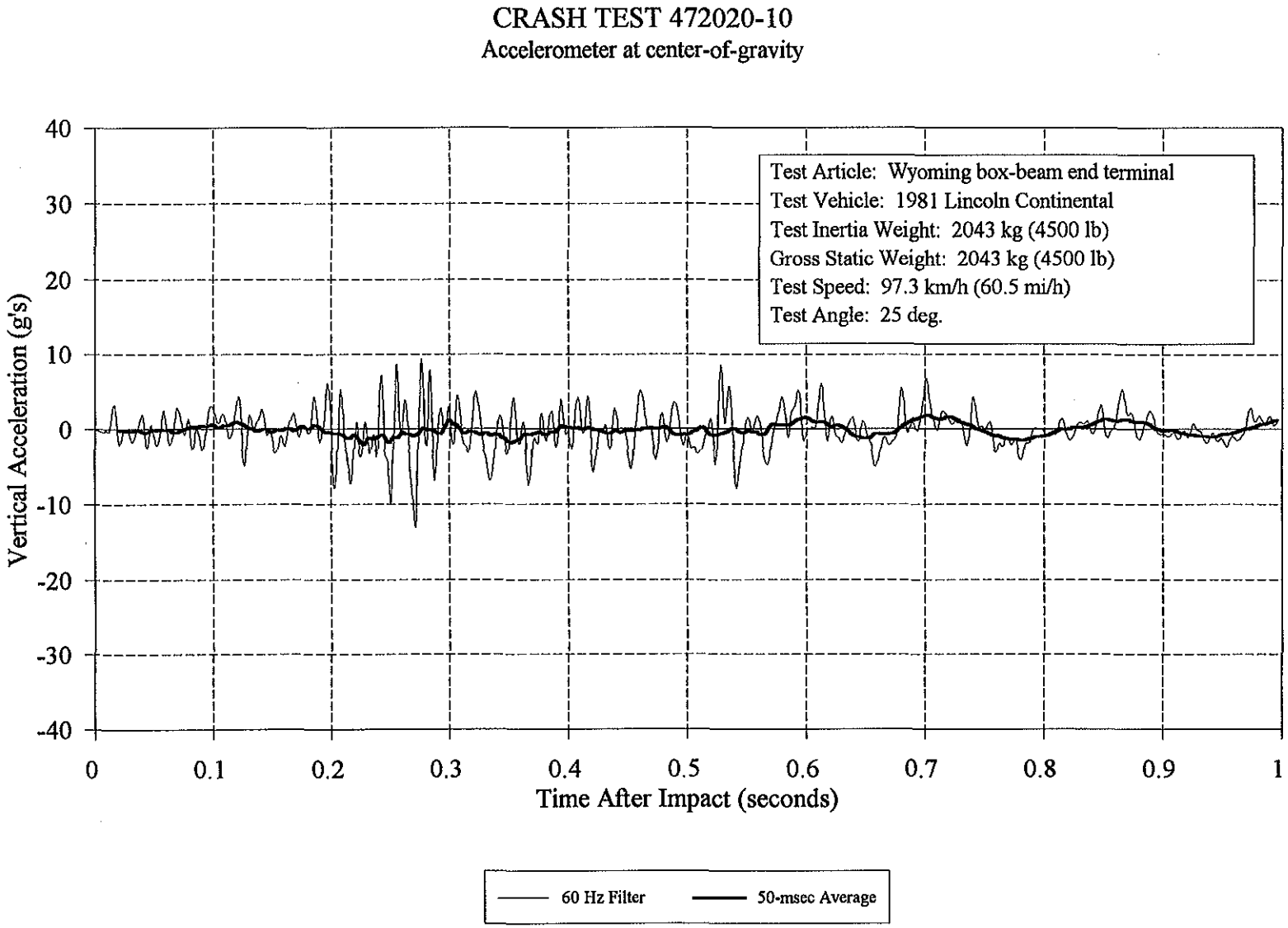


Figure 68. Vehicle vertical accelerometer trace for test 472020-10.

Also, the post angle and through bolt connection design was used for the entire 144 ft (43.9 m) of median barrier length-of-need in the test installation since it was unsure how many posts or sections of rail element with this positive connection would be required to contain and redirect the impacting vehicle. Based on the crash test results, it appears that this positive connection design is required only for a length of 54 ft (16.5 m), or the first three 18-ft (5.5-m) sections, of the median barrier rail element beyond which the standard slot-and-paddle connection can be used.

V. CONCLUSIONS AND RECOMMENDATIONS

In response to concerns expressed by FHWA, additional crash tests were conducted on the box-beam median barrier end terminal design. Results of the crash tests confirmed the validity of the concerns and the end terminal design was modified to alleviate the observed problems. The modified end terminal design was then crash tested and successfully met all evaluation criteria set forth in NCHRP Report 230.

The first concern was that the vehicle could potentially be wedged underneath the cable anchor, resulting in excessive deceleration on the vehicle prior to breaking of the wooden end post, as evidenced in the first small car reverse direction test (test no. 7202-6). The end terminal design was modified to include a standard 6-in. x 8-in. (152-mm x 203-mm) x 14 in. (356-mm) long wooden blockout attached to the top of the wooden end post to facilitate breaking of the wooden end post prior to the vehicle wedging underneath the cable anchor.

Another unexpected occurrence in the first small car reverse direction test was that the cable anchor bearing plate caught or snagged on the transmission housing of the vehicle, resulting in rapid yawing and abrupt deceleration of the vehicle. The bearing plate was therefore modified to include a slotted configuration which allows the bearing plate to separate from the cable anchor and minimize the potential of the bearing plate snagging on the undercarriage of the vehicle. The small car reverse direction test was rerun with the modified design (test no. 7202-7) and the end terminal performed satisfactorily. A summary of test results in shown in Table 1.

Also, the restraining cable for the impact head assembly was severed at the attachment to the gusset plate during the impact, allowing the impact head assembly to be thrown forward after disengaging from the outer tube. Examination of the severed restraining cable showed that the cable was partially cut by the sharp edges of the hole at the gusset plate during the previous test and thus failed to restrain the impact head assembly. This problem is minimized by incorporating cable thimbles for the restraining cable at the attachment points.

The second concern was that the median barrier end terminal design offers significantly less lateral resistance throughout its length. In the first large car length-of-need test (test no. 7202-8), the anchorage system failed with the foundation tube for the wooden end post pulled out of the ground. It was unclear from the crash test results if the anchorage failure was due to the reduced lateral stiffness of the end terminal or for other reasons. In any event, the anchorage was redesigned to

Table 1. Performance evaluation summary for test 472020-7.

Test No.: 472020-7 Test Date: 12/03/93 Test Agency: Texas Transportation Institute

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 Wyoming box-beam end terminal gated, allowing the vehicle to pass and exit the installation.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic	There was no debris from the vehicle or end terminal that might present undue hazard to vehicle occupants or other traffic	Pass
Occupant Risk		
E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	The vehicle remained upright and stable during the impact sequence and after exiting from the installation. There was essentially no deformation and no intrusion into the occupant compartment.	Pass
F. Impact severity shall be less than: Occupant Impact Velocity Limits - ft/s Longitudinal: 40/30 (Limit/Design) Lateral: 30/20 (Limit/Design) Occupant Ridedown Acceleration Limits - g's Longitudinal: 20/15 (Limit/Design) Lateral: 20/15 (Limit/Design)	Impact severity for this test were: Occupant Impact Velocity - ft/s (m/s) Longitudinal: 20.4 (6.2) Lateral: 5.7 (1.7) Occupant Ridedown Acceleration - g's Longitudinal: -1.5 Lateral: -1.8	Pass Pass
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	The vehicle came to rest behind the test installation, and did not pose any hazard to adjacent traffic.	Pass
I. In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less that 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	Vehicle exited the installation and subsequently came to rest behind the installation.	Pass
J. Vehicle trajectory behind the test article is acceptable.	The vehicle came to rest behind the installation.	Pass

provide greater anchorage capacity. Two alternate anchorage designs were developed: (1) weld a base plate to the bottom of the foundation tube for the wooden end post to increase the soil bearing capacity, and (2) embed the end post foundation tube in a concrete footing. The base plate design was considered the weaker design and was therefore selected for crash testing on the premise that, if the weaker design performed satisfactorily, the stronger design would work even better.

A second large car length-of-need test (test no. 7202-9) was conducted with the revised anchorage system. The vehicle was successfully redirected in the initial impact, but the rail element was detached from the posts ahead of the vehicle trajectory and fell to the ground under its own weight. The vehicle then turned back toward the barrier due to damage to the front tire and impacted the barrier a second time. Since the rail element was lying on the ground, the vehicle went over the rail element to go behind the barrier. It appears that this may be a problem inherent in the design of the connection between the rail element and the post of the median barrier itself and not necessarily related to the end terminal design. A more positive connection using a post angle and through bolt was incorporated into the design for the first several sections of the box-beam median barrier rail element. A third length-of-need strength test (test no. 7202-10) was then conducted with the revised connection design and met all evaluation criteria set forth under NCHRP Report 230 . A summary of the test results are shown in Table 2.

Based on results of the crash test, it appears that the 7/16-in. (11.1-mm) diameter bolt is stronger than needed and a 3/8-in (9.5-mm) diameter A307 bolt would have been adequate. Also, the positive connection design was used for the entire 150 ft (45.7 m) of median barrier length-of-need. It appears from the test results that this positive connection design is required only for a length of 54 ft (16.5 m), or the first three 18-ft (5.5-m) sections, of the median barrier rail element, beyond which the standard slot-and-paddle connection can be used. These changes are recommended for incorporation into the design.

The revised box-beam median barrier end terminal design successfully crash tested in this study was approved by FHWA for use on Federal-aid projects.[5] However, as with any new roadside safety appurtenances, it is recommended that the impact performance of this box-beam median barrier end terminal design be monitored for a period of time to identify any unforeseen problems that may show up in actual field installations. This would allow for timely correction of any identified problems, including minor design modifications, if necessary.

Table 2. Performance evaluation summary for test 472020-10.

Test No.: 472020-10 Test Date: 05/11/94 Test Agency: Texas Transportation Institute

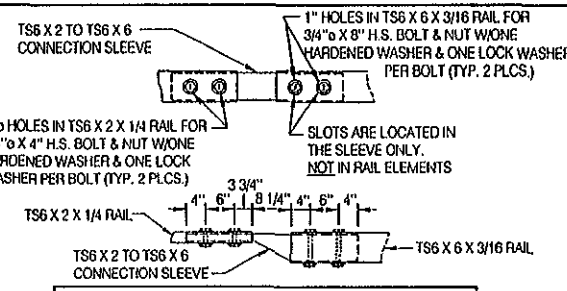
Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	The Wyoming box-beam end terminal contained and smoothly redirected the vehicle by controlled lateral deflection of the box-beam rail. The box-beam end terminal did not allow the vehicle to penetrate or go over the installation.	Pass
D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic	There was no debris from the vehicle or end terminal that might present undue hazard to vehicle occupants or other traffic.	Pass
Occupant Risk		
E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	The vehicle remained upright and stable during the impact sequence and after exiting from the installation. There was no deformation or intrusion into the occupant compartment.	Pass
Vehicle Trajectory		
H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Due to damage to both front tires, the vehicle came to rest 56 ft (17 m) forward of the point of impact with the installation.	Pass
I. In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less that 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	Exit speed is not available. Vehicle exited the installation at an angle of 14.4 deg, which is less than 15 deg, i.e. 60 percent of impact angle.	Pass

REFERENCES

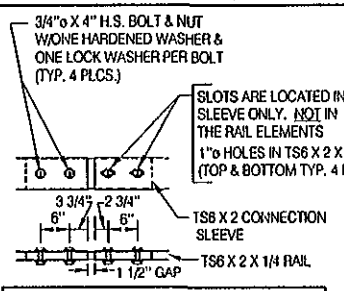
1. Mak, K. K., and Sicking, D. L., "Development of End Terminal for Box-Beam Guardrail, Phase I - Feasibility Study," Final report, Project No. RF 71740, prepared for Wyoming State Highway Department, Texas Transportation Institute, Texas A&M University, College Station, Texas, January 1992.
2. Mak, K. K., and Sicking, D. L., "Development of End Terminal for Box-Beam Guardrail, Phase II - Crash Testing and Evaluation," Final report, Project No. RF 72020, prepared for Wyoming State Highway Department, Texas Transportation Institute, Texas A&M University, College Station, Texas, September 1992.
3. Memorandum from Mr. Lawrence A. Staron to Mr. Louis MacDonald dated January 8, 1993.
4. Michie, J. D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, Washington, D. C., March 1981.
5. Letter from Mr. Seppo I. Sillan to Mr. King K. Mak dated June 23, 1994.

APPENDIX A

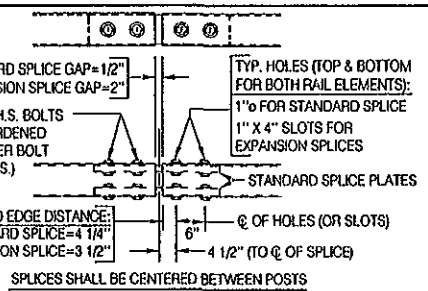
WYOMING DEPARTMENT OF TRANSPORTATION STANDARD DRAWINGS FOR BOX-BEAM GUARDRAIL, BOX-BEAM MEDIAN BARRIER, WY-BET AND WY-BET (MB) TERMINALS



TS6 X 2 TO TS6 X 6 RAIL CONNECTION DETAIL



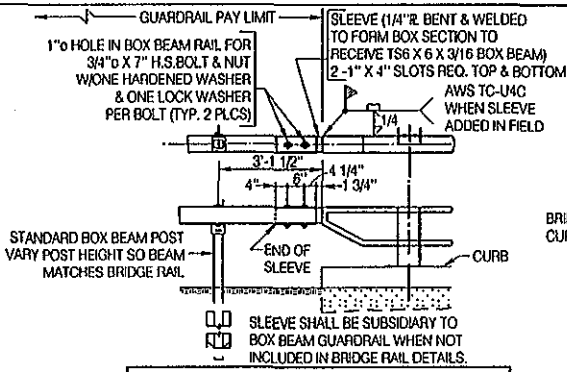
TS6 X 2 RAIL CONNECTION DETAIL



STANDARD RAIL SPLICE DETAIL

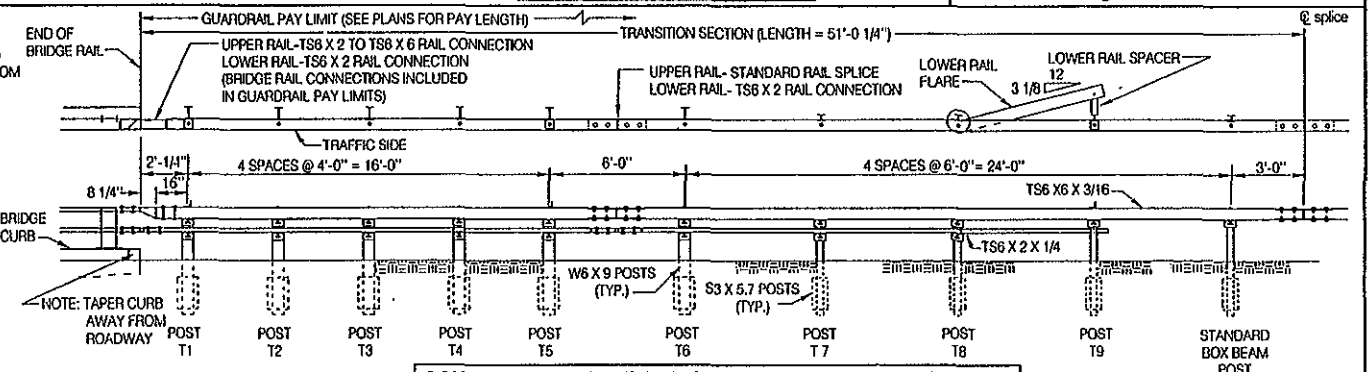
INSTALLATION NOTES

1. Standard Post Spacing=6'-0" unless otherwise shown. Minimum Post Spacing=4'-0".
2. Expansion Splices shall be placed in all box beam installations over 300 feet in length and shall be spaced at intervals not to exceed 500 feet.
3. Reflective tabs shall be placed every forth post. Reflective tabs shall not be used on WY-BET Terminals. Tabs shall be angled slightly towards traffic.
4. Unless approved otherwise, the minimum nominal rail length shall be 18 feet.



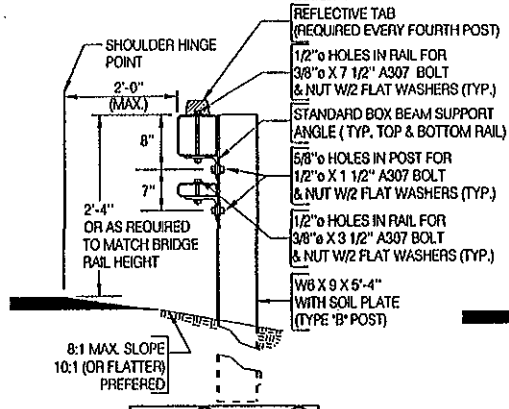
CONNECTION TO STEEL BRIDGE RAILING

(Exit ends of one-way traffic bridges i.e. divided highways)

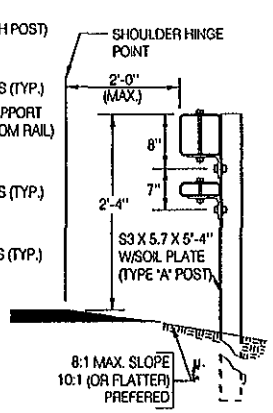


CONNECTION TO STEEL BRIDGE RAILING (TRANSITION SECTION)

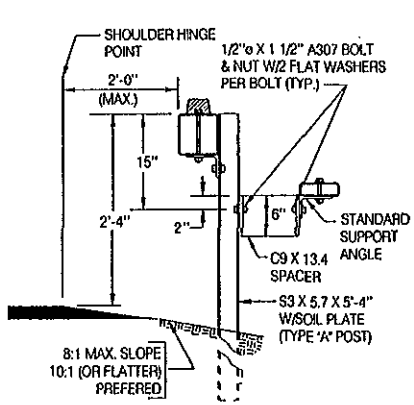
(ALL ends of two-way traffic bridges and entrance ends of one way traffic bridges, i.e. divided highways)



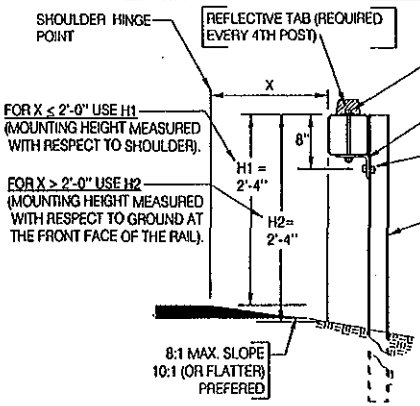
POST (T1) THRU (T6)



POST (T7) & (T8)



POST (T9)



STANDARD BOX BEAM POST (TYPICAL)

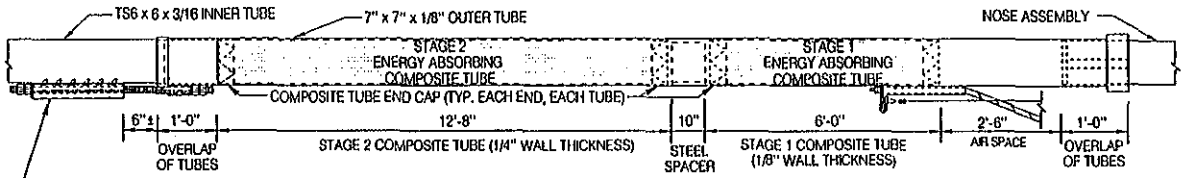
WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL

(BOX BEAM ASSEMBLY DETAILS)

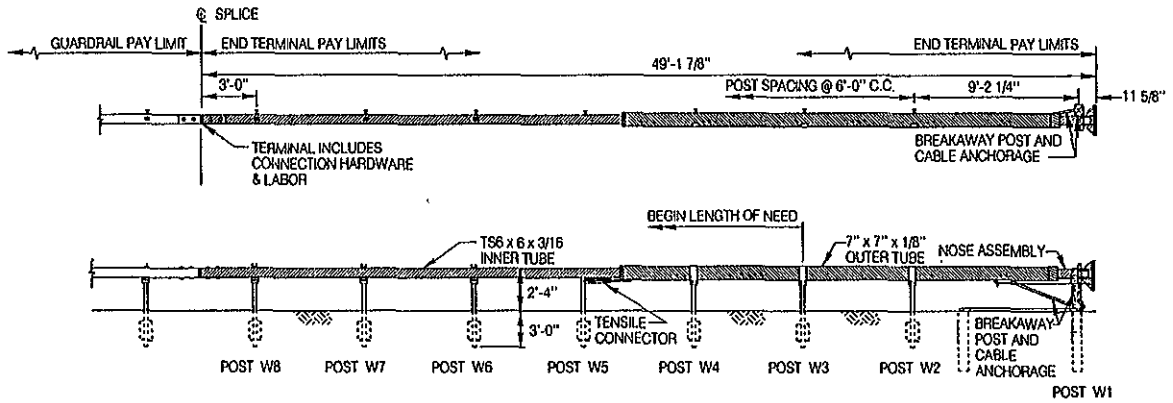
Date Issued		STANDARD PLAN NUMBER
Designed by	WBW	Sheet 1
Drawn by	NEO	
Checked by		

123



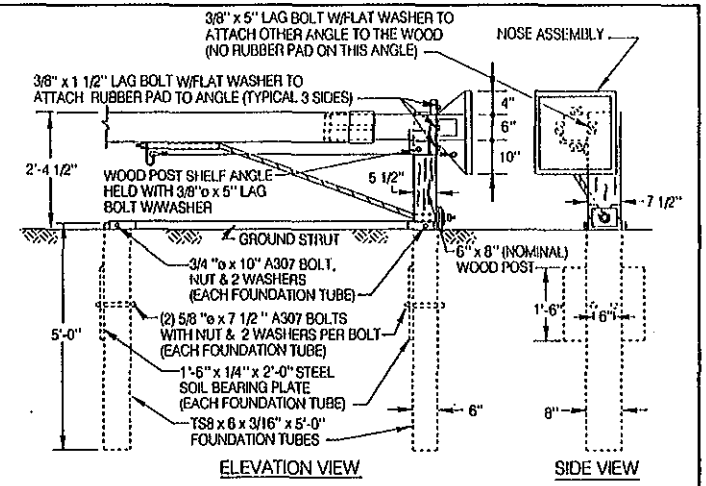
INTERNAL COMPONENTS OF 7" x 7" x 1/8" OUTER TUBE

NOTE: End caps must be securely attached to the tuluped ends of each composite tube with a double wrap of 4 inch wide duct tape.

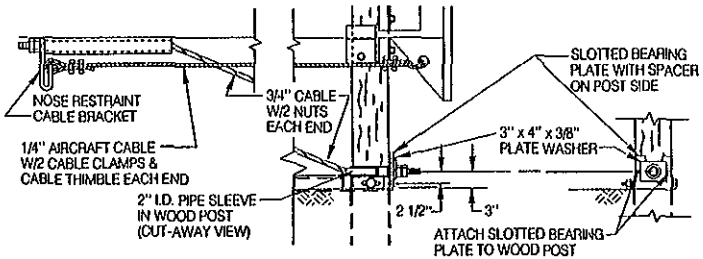


PLAN & ELEVATION VIEW -- WY-BET END TERMINAL

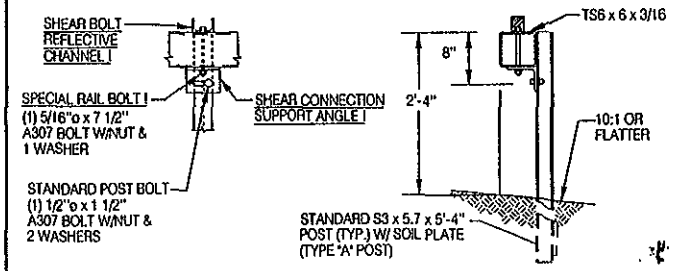
(RIGHT HAND UPSTREAM INSTALLATION SHOWN)



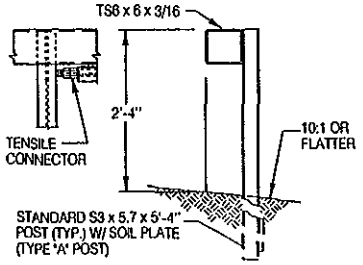
WYBET POST W1
(WOOD BREAKAWAY CABLE ANCHOR POST)



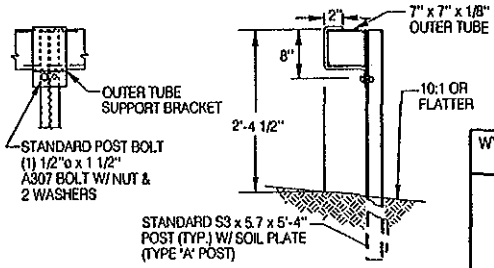
NOTE: Cables shall be taught.



WYBET POST W6 - W8
(SHEAR CONNECTION)



WYBET POST W5
(NO HARDWARE CONNECTION)



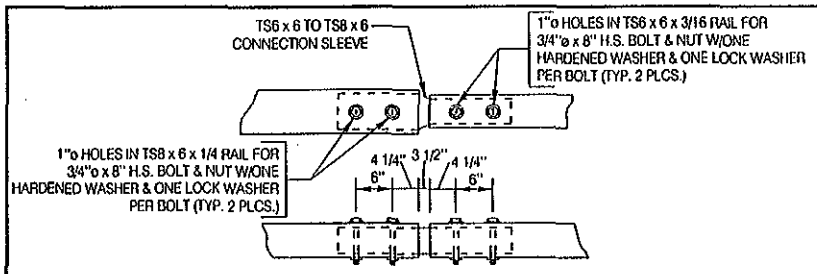
WYBET POST W2 - W4
(SLIDE CONNECTION)

WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

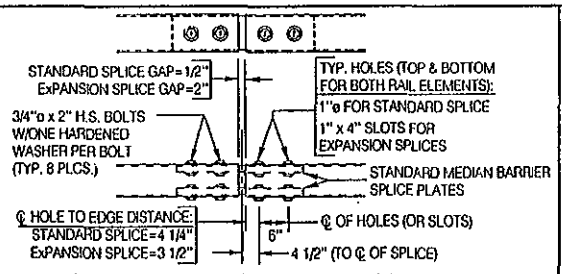
BOX BEAM GUARDRAIL

(WY-BET ASSEMBLY DETAILS)

Designed	WAW	STANDARD PLAN NUMBER
Drawn	WAW	
Checked	REO	Sheet 2
Date		



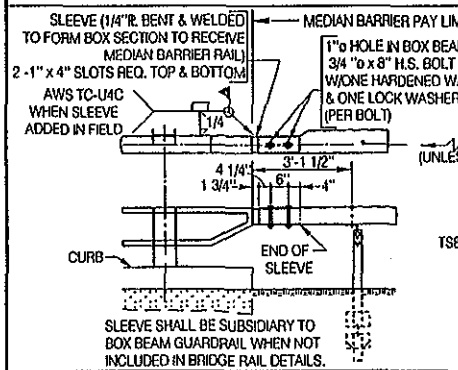
TS6 x 6 TO TS8 x 6 RAIL CONNECTION DETAIL



MEDIAN BARRIER SPLICE DETAIL

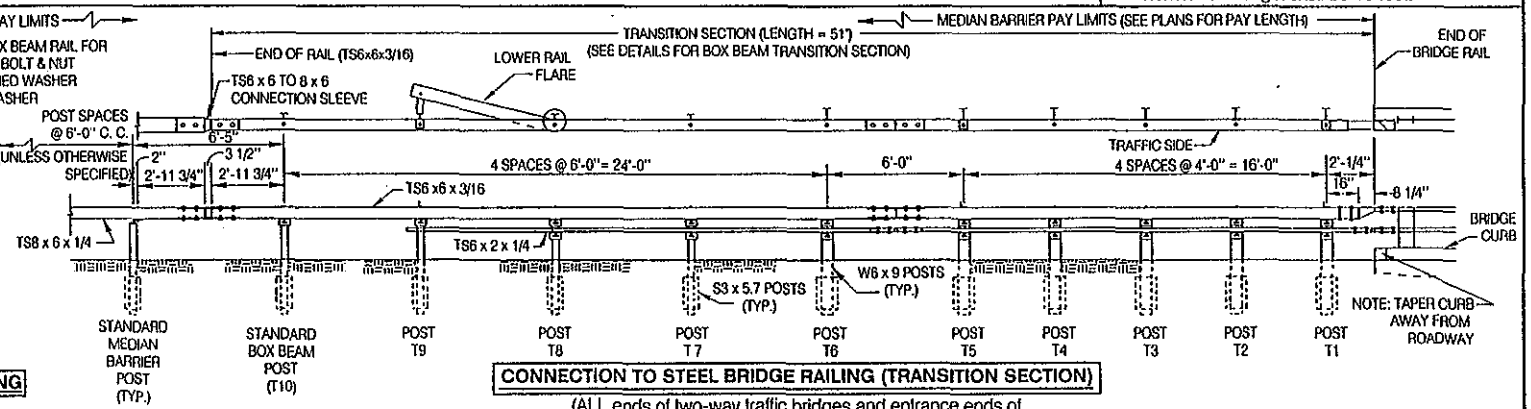
INSTALLATION NOTES

1. Standard Post Spacing=6'-0" unless otherwise shown. Minimum Post Spacing=4'-0".
2. Expansion Splices shall be placed in all box beam installations over 300 feet in length and shall be spaced at intervals not to exceed 500 feet.
3. Reflective tabs shall be placed every forth post. Reflective tabs shall not be used on WY-BET Terminals. Tabs shall be angled slightly towards traffic.
4. Unless approved otherwise, the minimum nominal rail length shall be 18 feet.



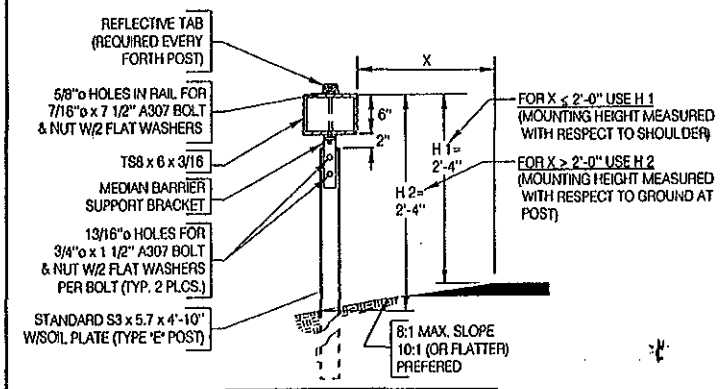
CONNECTION TO STEEL BRIDGE RAILING

(Exit ends of one-way traffic bridges i.e. divided highways)

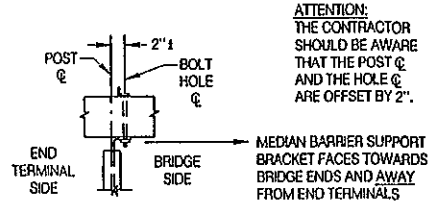


CONNECTION TO STEEL BRIDGE RAILING (TRANSITION SECTION)

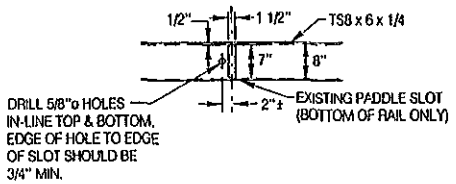
(ALL ends of two-way traffic bridges and entrance ends of one way traffic bridges, i.e. divided highways)



STANDARD MEDIAN BARRIER POST (TYPICAL)



PARTIAL ELEVATION VIEW



MODIFYING EXISTING PADDLE MOUNTED MEDIAN BARRIER TO STANDARD MEDIAN BARRIER CONNECTION.

WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL

(BOX BEAM MEDIAN BARRIER ASSEMBLY DETAILS)

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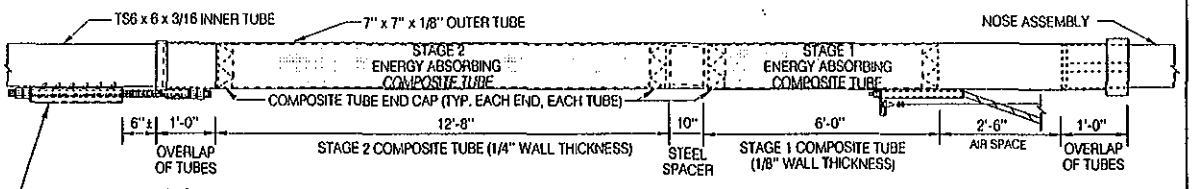
Designed by	WBW	Sheet 3
Drawn by	RED	
Checked by		

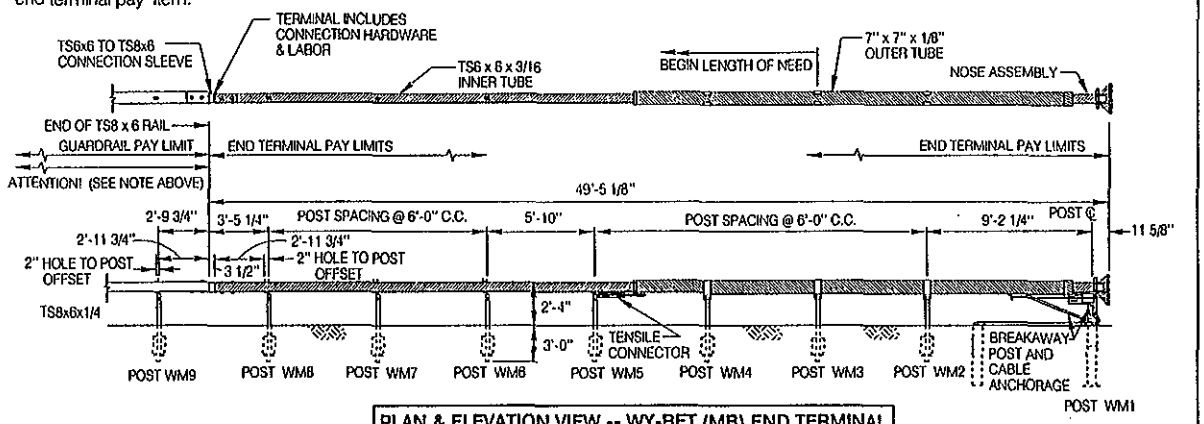
125



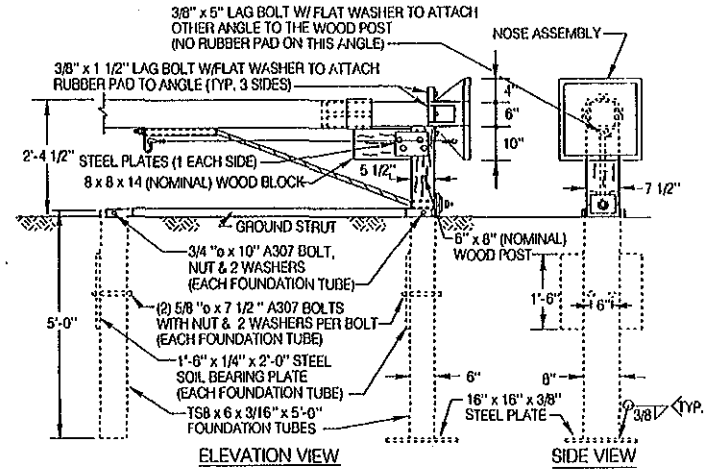
INTERNAL COMPONENTS OF 7" x 7" x 1/8" OUTER TUBE

NOTE: End caps must be securely attached to the tuluped ends of each composite tube with a double wrap of 4 inch wide duct tape.

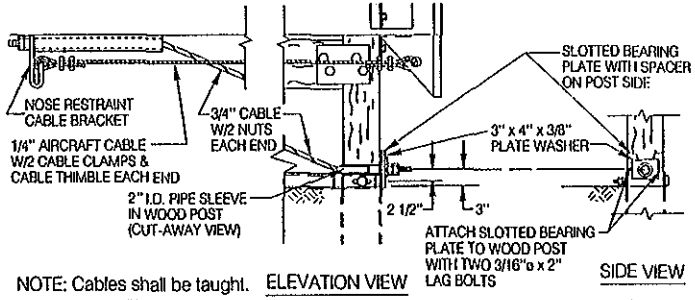
ATTENTION! Where WY-BET (MB) connects to an existing paddle mounted median barrier system, a "Positive Connection" as shown below, must be installed 10 posts beyond the end terminal. The Contractor shall modify these post connections (identified as WM9 - WM18) as a part of the end terminal pay item.

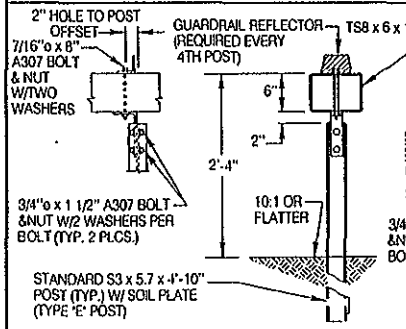


PLAN & ELEVATION VIEW -- WY-BET (MB) END TERMINAL

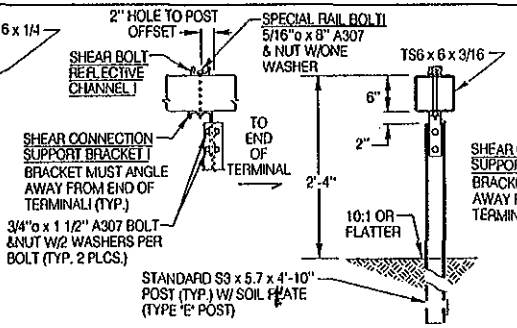


WYBET (MB) POST WM1 (WOOD BREAKAWAY CABLE ANCHOR POST)

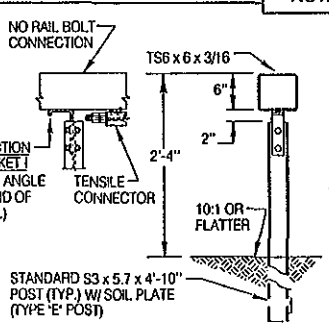




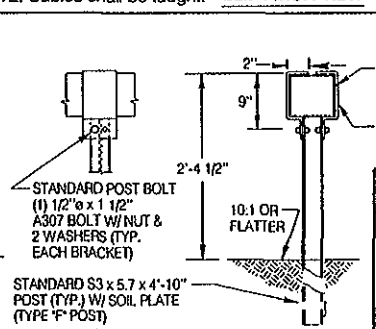
WYBET (MB) POST WM9 - WM18 (POSITIVE CONNECTION)



WYBET (MB) POST WM6 - WM8 (SHEAR CONNECTION)



WYBET (MB) POST WM5 (NO RAIL BOLT CONNECTION)

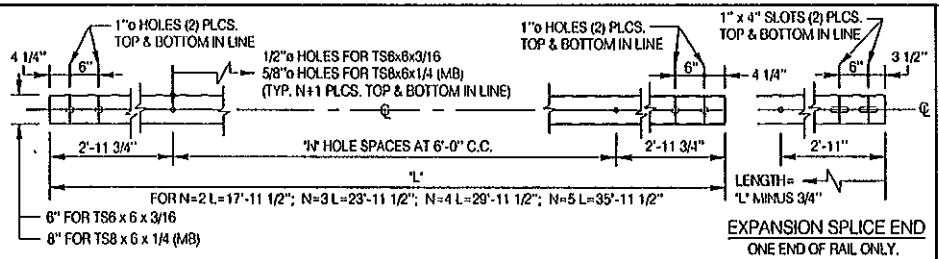


WYBET (MB) POST WM2 - WM4 (SLIDE CONNECTION)

WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL
(WY-BET (MB) MEDIAN BARRIER ASSEMBLY DETAILS)

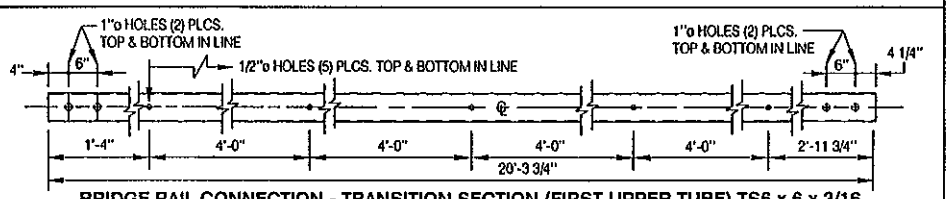
Date Issued		STANDARD PLAN NUMBER
Quantity	WBW	Sheet 4
Drawn By	RED	
Checked By		



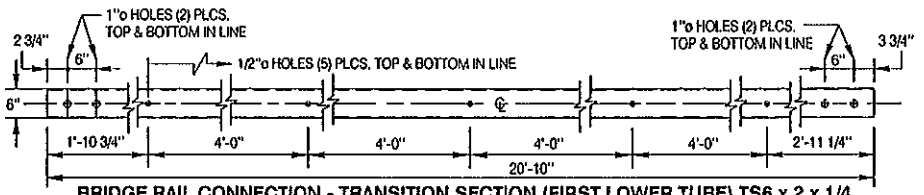
EXPANSION SPLICE END
ONE END OF RAIL ONLY. REQ'D FOR BOTH RAILS AT THE EXPANSION SPLICE.

STANDARD RAIL ELEMENTS (6'-0" POST SPACING) FOR:

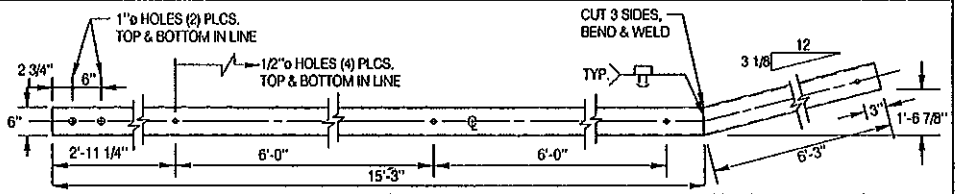
1) BOX BEAM GUARDRAIL TS6x6x3/16
2) BOX BEAM MEDIAN BARRIER (MB) TS8x6x1/4



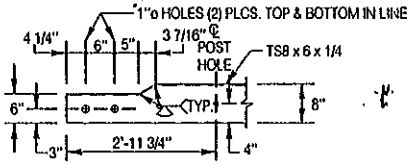
BRIDGE RAIL CONNECTION - TRANSITION SECTION (FIRST UPPER TUBE) TS6 x 6 x 3/16



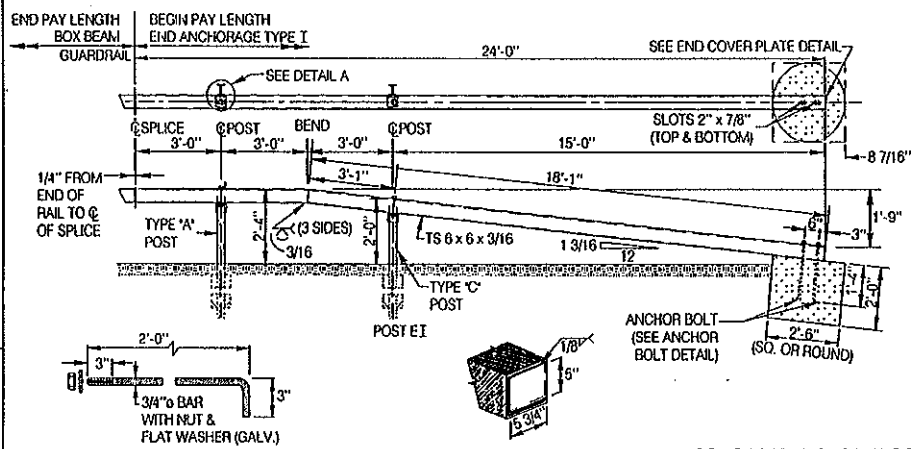
BRIDGE RAIL CONNECTION - TRANSITION SECTION (FIRST LOWER TUBE) TS6 x 2 x 1/4



BRIDGE RAIL CONNECTION - TRANSITION SECTION (FLARED LOWER TUBE) TS6 x 2 x 1/4



EXIT END BRIDGE CONNECTION DETAIL FOR MEDIAN BARRIER RAIL

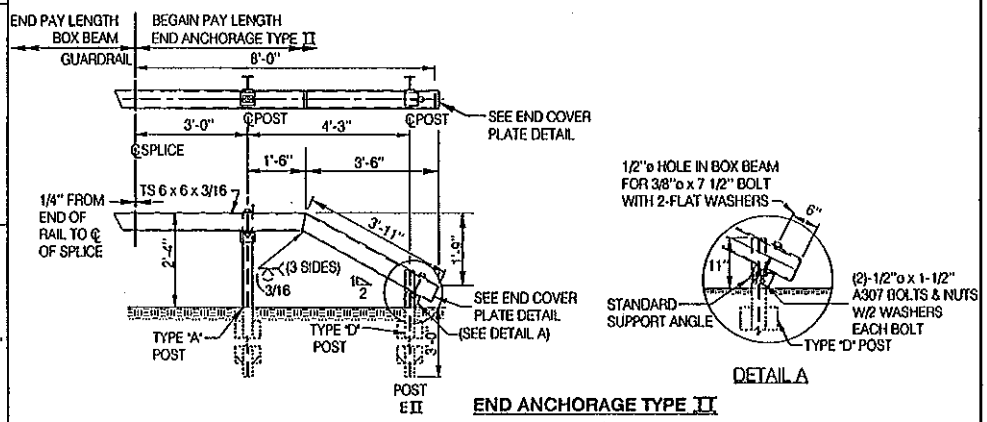


ANCHOR BOLT DETAIL

END COVER PLATE DETAIL
(BAR 5 x 3/16" x 0'-5 3/4")

CONCRETE ANCHOR BLOCK
(CLASS B CONCRETE, PRE-CAST OR CAST-IN-PLACE)

END ANCHORAGE TYPE I



DETAIL A

END ANCHORAGE TYPE II

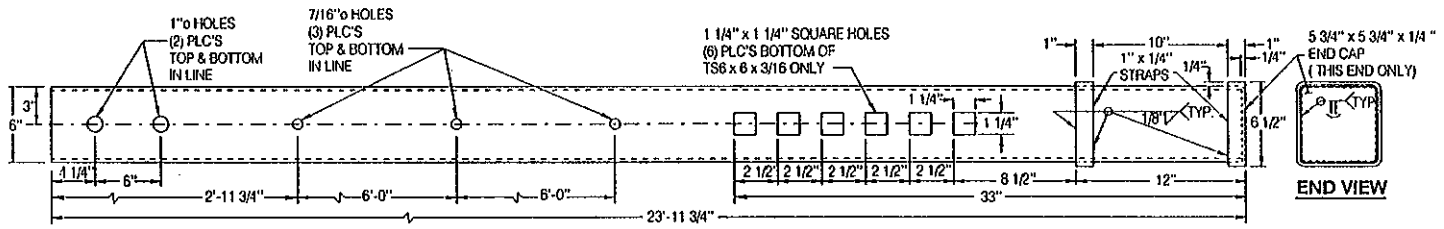
GENERAL FABRICATION NOTES

1. Typical rail elements are depicted here. It is desirable to use standard rail elements wherever possible, however certain guardrail layouts may require adjustment of these details..
2. All welding shall be completed prior to galvanizing.

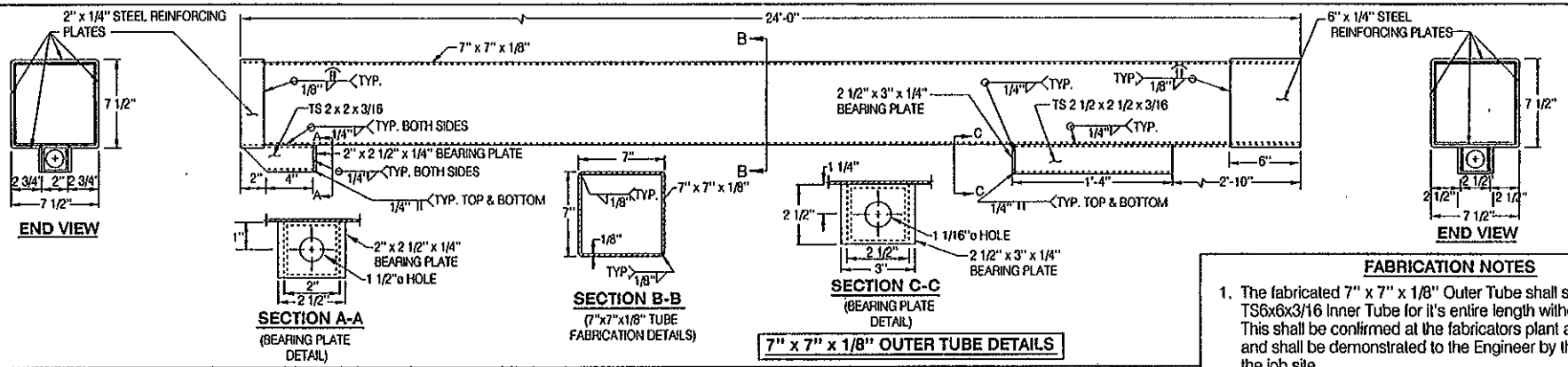
WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL
(RAIL FABRICATION, END ANCHORAGE FABRICATION AND ASSEMBLY DETAILS)

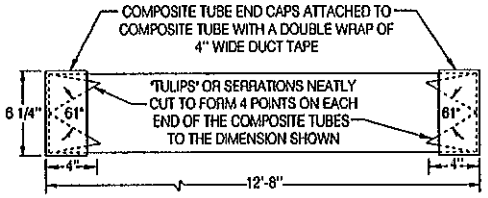
Date Issued		STANDARD PLATE NUMBER
Designed by	WBW	Sheet 5
Quantity	RED	
Checked by		



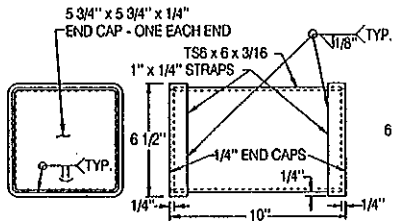
TS6 x 6 x 3/16 INNER TUBE DETAILS



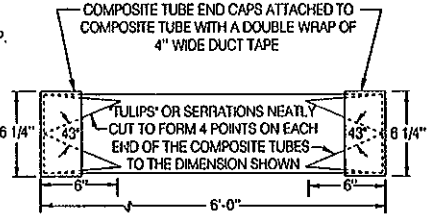
7" x 7" x 1/8" OUTER TUBE DETAILS



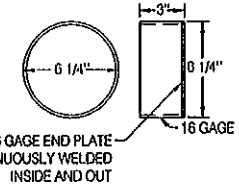
12'-8" COMPOSITE TUBE (STAGE 2)
(6"o x 1/4" WALL THICKNESS)



INTERMEDIATE SPACER DETAILS



6'-0" COMPOSITE TUBE (STAGE 1)
(6"o x 1/8" WALL THICKNESS)



COMPOSITE TUBE END CAP DETAIL (TYP.)

INTERNAL COMPONENTS OF 7" x 7" x 1/8" OUTER TUBE

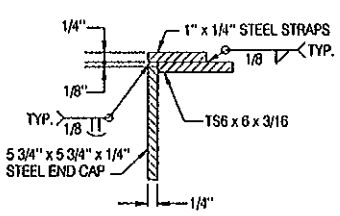
FABRICATION NOTES

1. The fabricated 7" x 7" x 1/8" Outer Tube shall slide freely over the TS6x6x3/16 Inner Tube for it's entire length without any binding. This shall be confirmed at the fabricators plant after galvanization and shall be demonstrated to the Engineer by the Contractor on the job site.
2. Proper performance of the end terminal depends on maintaining a relatively low mass for the 7 x 7x 1/8" Outer Tube, therefore the wall thickness cannot be altered.
3. The 1" x 1/4" steel reinforcing straps shall extend 1/4" beyond the end of the 6 x 6 x 3/16" tubes for the inner tube and the intermediate spacer to facilitate welding of the end caps. A 1/8" gap all around the end cap shall be maintained to facilitate a good weld all around the end cap.
4. Two-1/2" holes may be drilled in the side of the intermediate spacer to act as vent holes during galvanization.
5. Strapes & plates shall be A36 steel.
6. Welding shall be completed prior to galvanization.

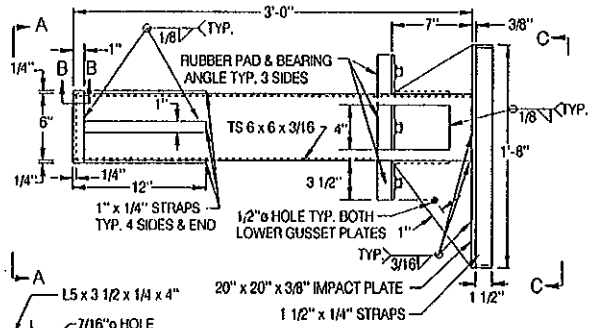
WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

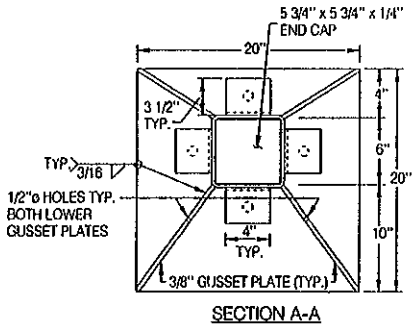
BOX BEAM GUARDRAIL
(WY-BET & WY-BET (MB)
TUBE FABRICATION DETAILS)

		STANDARD PLAN NUMBER
Date Issued		
Designed by	WBW	Sheet 6
Drawn by	RED	
Checked by		

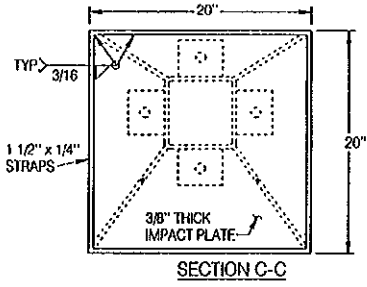


SECTION B-B
(End cap weld detail)

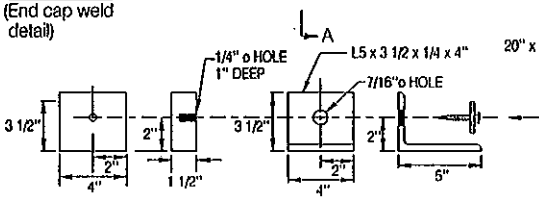




SECTION A-A



SECTION C-C



RUBBER PAD
(3 Req.)

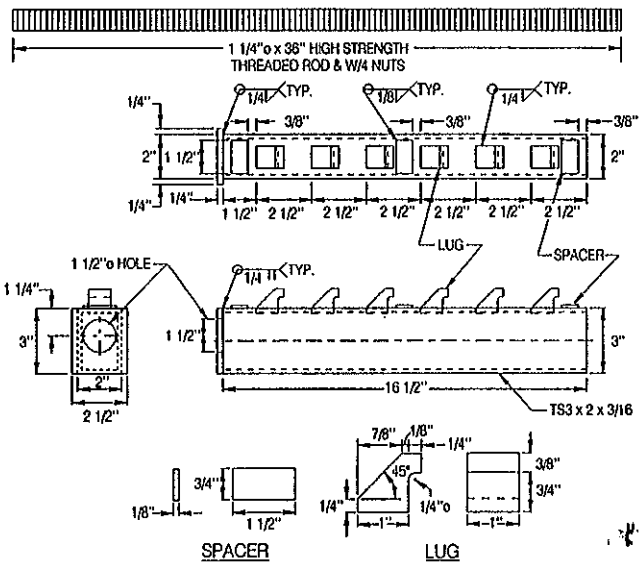
BEARING ANGLE
(4- Req.-weld to nose assembly as shown above)

Attach rubber pad to bearing angle with 3/8" x 1 1/2" lag bolt & washer on three angles. Forth angle bears directly against wood post and requires a 3/8" x 5" lag bolt & washer, screwed into post.

NOSE ASSEMBLY FABRICATION DETAILS

FABRICATION NOTES

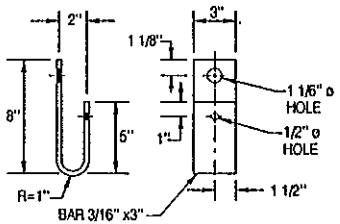
1. 2-1/2"ø Venting and pick-up holes may be drilled into each end of end section on bottom to facilitate galvanization.
2. 1" x 1/4" Straps overlap TS6 x 6 x 3/16 by 1/4".
3. Maintain a 1/8" gap between end cap and 1" x 1/4" straps for welding.
4. Straps and plates shall be A36 steel.



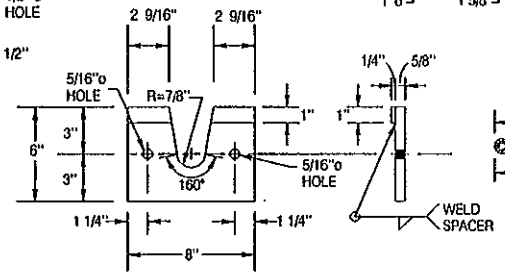
SPACER

LUG

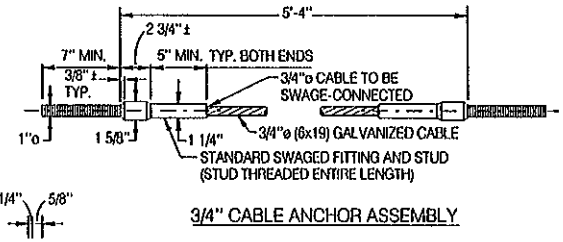
TENSILE CONNECTOR FABRICATION DETAILS



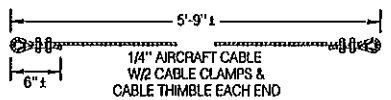
NOSE RESTRAINT
CABLE BRACKET



SLOTTED BEARING PLATE



3/4" CABLE ANCHOR ASSEMBLY



NOSE RESTRAINT CABLE

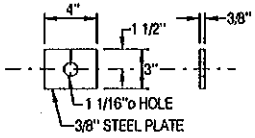
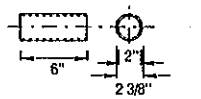


PLATE WASHER



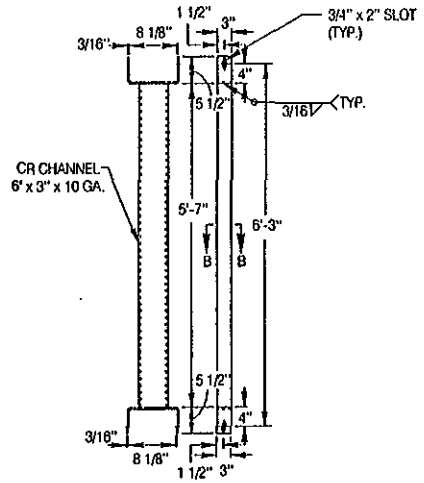
BREAKAWAY TERMINAL
POST SLEEVE

CABLE ANCHOR FABRICATION DETAILS

WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

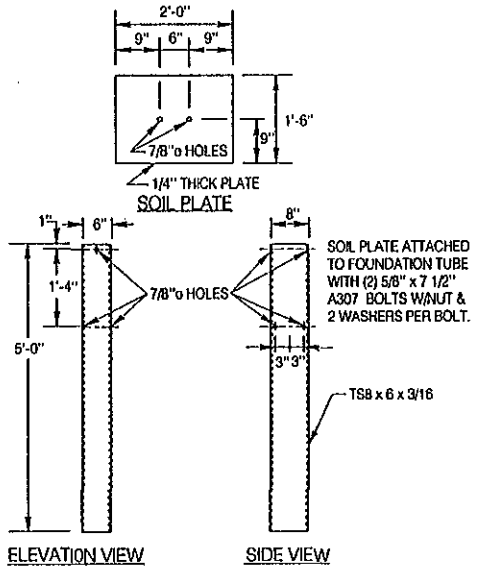
BOx BEAM GUARDRAIL
(WY-BET & WY-BET (MB)
NOSE & ANCHORAGE FABRICATION DETAILS)

Date Issued		STANDARD PLAN NUMBER
Designed by	WBW	Sheet 7
Drawn by	REO	
Checked by		



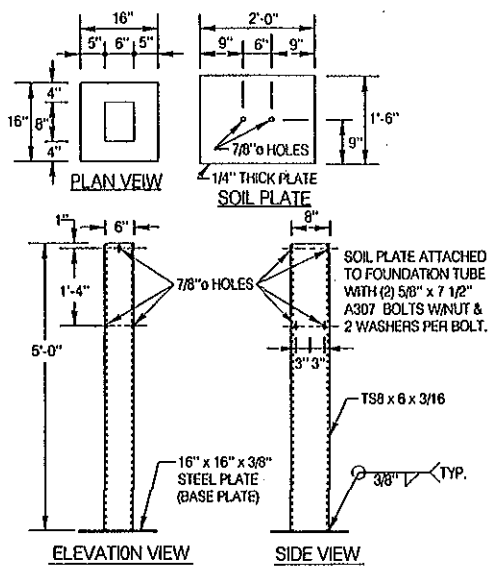
FOUNDATION TUBE GROUND STRUT

1 Req'd for WY-BET
1 Req'd for WY-BET (MB)



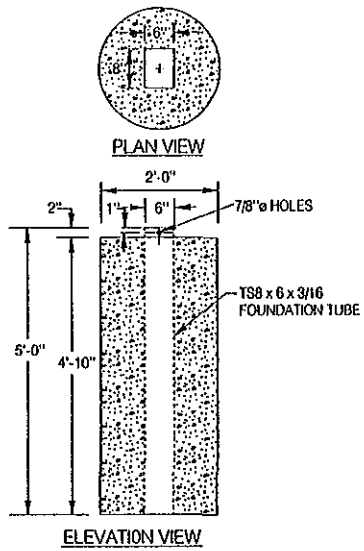
STANDARD FOUNDATION TUBE (INCL. SOIL PLATE)

2 Req'd for WY-BET
1 Req'd for WY-BET (MB) plus 1 foundation tube with base plate



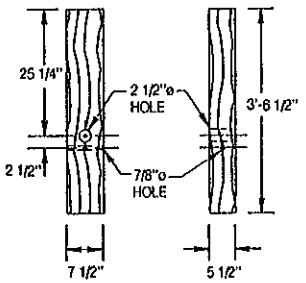
FOUNDATION TUBE WITH BASE PLATE (INCL. SOIL PLATE)

1 Req'd for WY-BET (MB)



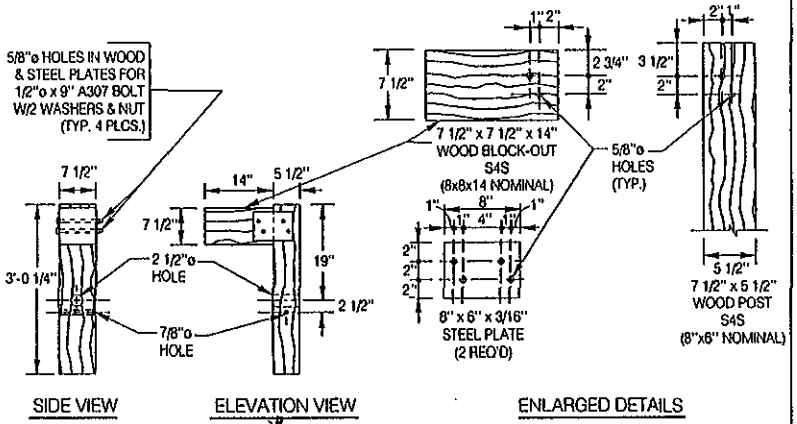
ALTERNATE FOUNDATION SYSTEM FOR WY-BET & WY-BET (MB)

(Replaces two foundation tubes and ground strut)



WY-BET BREAKAWAY WOOD POST

(WY-BET Post W1)



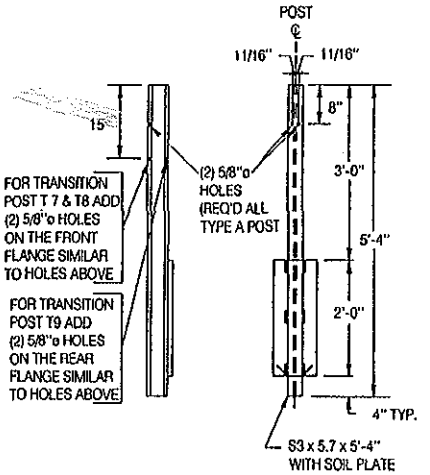
WY-BET (MB) BREAKAWAY WOOD POST

(WY-BET (MB) Post WM1)

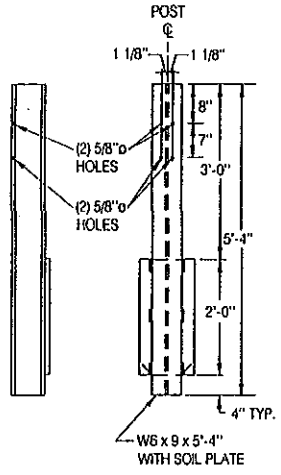
WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL
(WY-BET &WY-BET (MB)
WOOD POST & FOUNDATION
TUBE FABRICATION DETAILS)

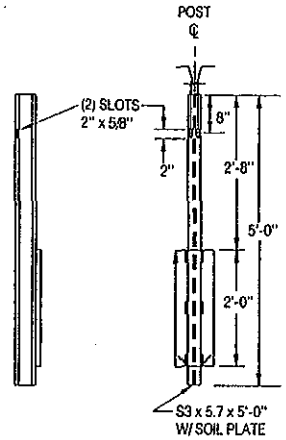
Detailed		STANDARD PLAN TS&B-6(21)
Designed by	WBW	
Drawn by	REO	Sheet 8
Checked by		



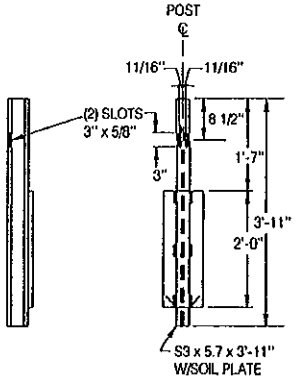
TYPE "A" POST
(STANDARD BOX BEAM POST)
FOR: 1) STANDARD BOX BEAM GUARDRAIL RUNS
2) TRANSITION POST T 7-T10
3) WY-BET POST W2-W8
4) END ANCHORAGE TYPE I



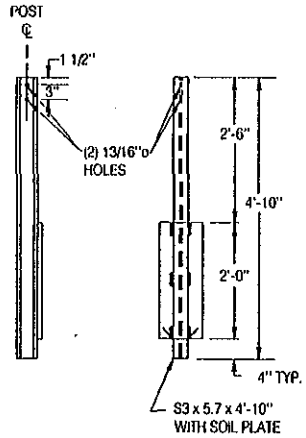
TYPE "B" POST
FOR: 1) TRANSITION POST T1-T6



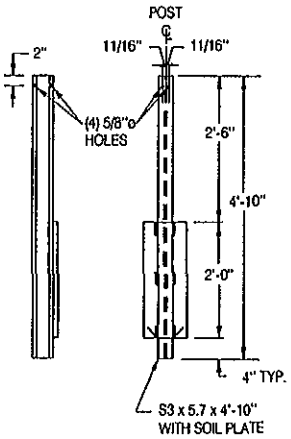
TYPE " C" POST
FOR: BB END ANCHORAGE TYPE I
POST E I



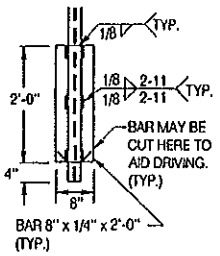
TYPE "D" POST
FOR: BB END ANCHORAGE TYPE II
POST E II



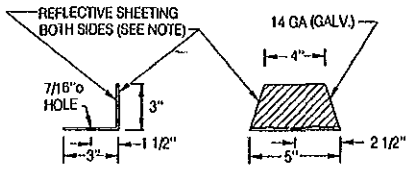
TYPE "E" POST
(STANDARD MEDIAN BARRIER POST)
FOR: 1) STANDARD MEDIAN BARRIER RUNS
2) WY-BET (MB) POST WM5 - WM8



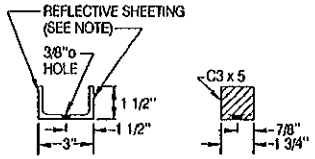
TYPE "F" POST
FOR: WY-BET (MB) POST WM2-WM4



TYPICAL SOIL PLATE DETAIL



REFLECTIVE TAB DETAIL
A reflective tab shall be placed on every fourth post for standard runs of Box Beam & Box Beam Median Barrier. Reflective tabs shall not be used on WY-BET Terminals.



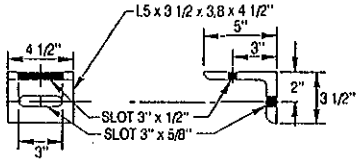
SHEAR BOLT REFLECTIVE CHANNEL DETAIL
To be used at each WY-BET & WY-BET (MB) shear connection (i.e. post W6-W8, & WM6-WM8)

NOTE: Reflective sheeting shall meet the requirements for Type II or Type III reflective sheeting in the standard specifications. Reflective sheeting shall be yellow for all median installations and white for all shoulder installations.

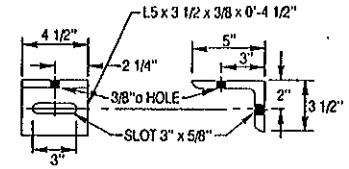
WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL
(STEEL POST & REFLECTIVE HARDWARE FABRICATION DETAILS)

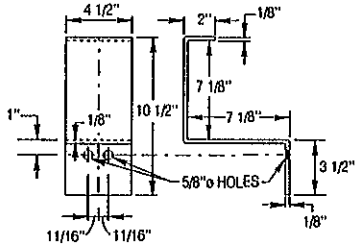
Designed by	WBW	STANDARD PLAN NUMBER
Drawn by	RED	Sheet 9
Checked by		



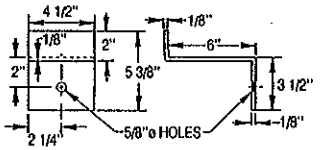
STANDARD BOX BEAM SUPPORT ANGLE



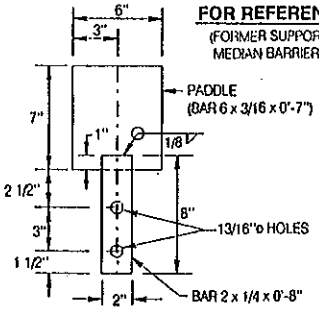
WY-BET SHEAR CONNECTION SUPPORT ANGLE



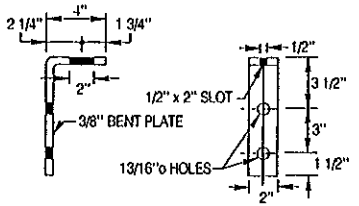
WY-BET OUTER TUBE SUPPORT BRACKET



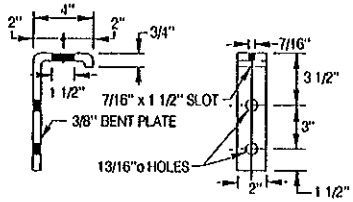
WY-BET NOSE SUPPORT BRACKET



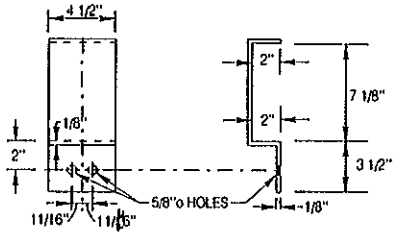
MEDIAN BARRIER SUPPORT PADDLE



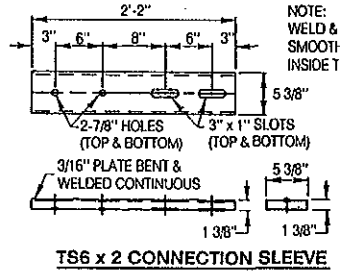
MEDIAN BARRIER SUPPORT BRACKET



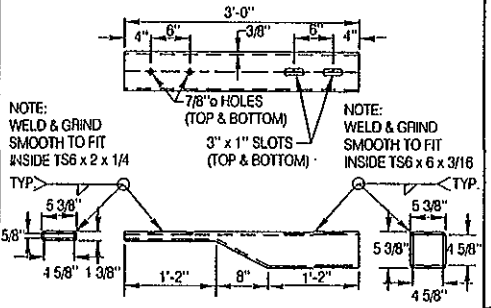
WY-BET (MB) SHEAR CONNECTION SUPPORT BRACKET



WY-BET (MB) OUTER TUBE SUPPORT BRACKET
(2 REQ'D PER POST)

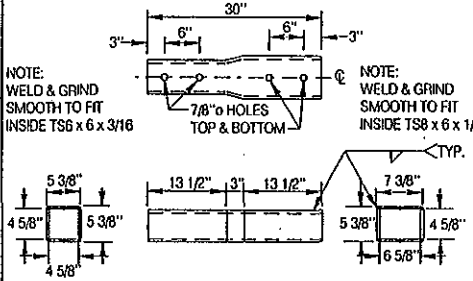


TS6 x 2 CONNECTION SLEEVE



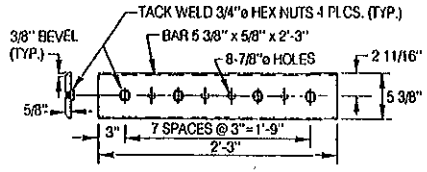
NOTE: Fabricate sleeve from 3/8" A36 steel. Cut top & side walls to shape. Bend bottom wall as shown.

TS6 x 2 TO TS6 x 6 CONNECTION SLEEVE

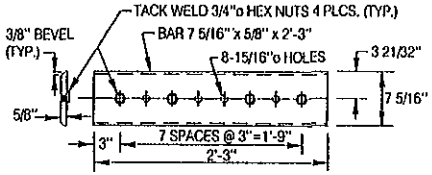


NOTE: Sleeve fabrication from 3/8" A36 steel. Top & bottom walls shall each be cut from continuous steel plate. Side walls shall be welded at all junctions.

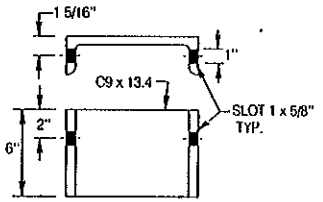
TS6 x 6 TO TS8 x 6 CONNECTION SLEEVE



STANDARD BOX BEAM SPLICE PLATE
(2 Req'd per splice)



STANDARD BOX BEAM (MB) MEDIAN BARRIER SPLICE PLATE
(2 Req'd per splice)



LOWER RAIL SPACER DETAIL

WYOMING DEPARTMENT OF TRANSPORTATION
STANDARD PLAN

BOX BEAM GUARDRAIL
(MISC. CONNECTION HARDWARE FABRICATION DETAILS)

Date Issued		STANDARD PLAN NUMBER
Designed by	WBW	
Drawn by	REG	Sheet 10
Checked by		

APPENDIX B

REVISIONS TO DESIGN DETAILS

A number of revisions were made to the design details of the box-beam median barrier and the WY-BET (MB) terminal by the Wyoming Department of Transportation, as shown in Appendix A. Brief descriptions and discussions of the revisions to the design details are presented in this appendix.

- The nose restraint cable assembly was modified and added to the shoulder barrier version of WY-BET terminal (see Sheets 2, 4, 7 and 10 of the Standard Drawings). The modifications to the nose restraint cable assembly include a redesigned bracket that would yield at a force of approximately 200 lb (90.7 kg). The length of the restraining cable is shortened so that the cable would remain taut under normal conditions, but upon impact and yielding of the bracket, the cable would extend so that the nose piece would almost come off the outer tube. The rationale for the modifications to the nose restraint cable assembly was that, in addition to restraining the nose piece from flying off in reverse direction impacts, the cable should also prevent the nose piece from coming off as a result of vandalism or vibration. It is therefore desirable to maintain tension on the cable, making it less likely for the nose piece to come off. A longer restraint cable was used with the test installation over concern that, if the cable was not long enough to allow the nose piece to completely separate from the outer tube, it might act as snagging point for the reverse direction impact. However, it was observed in the reverse direction crash tests that the outer tube and the nose piece would quickly swing out of the way of the vehicle. It is, therefore, highly unlikely that the nose piece would act as a snag point. The yield strength of 200 lb (90.7 kg) is relatively small compared to the forces experienced during a crash test and it would function properly as long as the bracket has a strength equal to or higher than the cable so that it will not break before the cable.
- Two 1/2-in (12.7-mm) diameter bolts are used instead of one bolt for the outer tube support bracket for maintenance consideration (see Sheet 2 of the Standard Drawings). The additional bolt should not pose any snagging problem given the thin gauge of the bracket. The height of the bolt holes are revised to allow for use of standard box-beam posts to reduce the need for special fabrications.

- For new construction, the details for mounting the median barrier rail element to the posts in the length-of-need sections have been changed from the use of paddles to a more positive connection with 7/16-in. (11.1-mm) diameter bolts (see Sheet 2 of the Standard Drawings). This will prevent the rail element from being lifted off the paddles as observed in the full-scale crash tests. For existing median barrier installations with paddle mounts, a positive connection is used for the first 10 posts beyond the terminal.
- For transition to bridge railings, the same transition section used for box-beam guardrails is used for the median barrier (see Sheet 3 of the Standard Drawings). Given that the length of the transition section is only 48 feet (14.6 m) long, the probability of a vehicle impacting the back side of the transition is very remote and should not pose any problem.
- The rail height for the median barrier is changed from 30 in. (762 mm) to 28 in. (711 mm) so as to be consistent with that of the shoulder barrier (see Sheet 3 of the Standard Drawings). This should not have any adverse effect on the impact performance of the median barrier. It may actually improve the impact performance for small vehicles since it would reduce the height of the opening from the ground to the bottom of the rail element.
- The connection between the TS 8 in. x 6 in. (203 mm x 152 mm) and the TS 6 in. x 6 in. (152 mm x 152 mm) rail elements has been modified to use a sleeve instead of the splice plates (see Sheets 4 and 10 of the Standard Drawings). The sleeve should strengthen the connection and make the connection less dependent on the quality of the welds. The taper in the sleeve should also minimize the potential for snagging on the end of TS 8 in. x 6 in. (203 mm x 152 mm) rail element which has a protrusion of 1 in. (25.4 mm) when transitioning from the TS 6 in. x 6 in. (152 mm x 152 mm) rail element.
- The size of the holes cut into the TS 6 in. x 6 in. x 3/16 in. (152 mm x 152 mm x 4.8 mm) inner tube is increased from 1 in. x 1-1/4 in. (25.4 mm x 31.8 mm) to 1-1/4 in. x 1-1/4 in. (31.8 mm x 31.8 mm) to facilitate easier assembly of the tensile connector (see Sheet 6 of the Standard Drawings).
- To accommodate the 28-in. (711-mm) rail mounting height, the length of the breakaway wooden end post is changed from 2 ft 11-1/2 in. (902 mm) to 3 ft 1/4 in. (921 mm) and the dimension from the bottom of the post to the center of the foundation tube bolt hole is changed from 15-1/2 in. (394 mm) to 14-3/4 in (375 mm). (see Sheet 8 of the Standard Drawings).

- The dimensions of the outer tube support bracket dimensions are changed to accommodate flush post mounting (see Sheet 10 of the Standard Drawings).
- The WY-BET and WY-BET (MB) terminals are designed and tested as tangent terminals, i.e., the terminal section is parallel to the travelway. However, in field installations, it may sometimes be desirable to flare the terminal section away from the travelway to increase the offset of the terminal nose or to reduce the length of the length-of-need section. For such flared installations, it is recommended that a flare rate of no more than 15:1 be used to assure proper functioning of the terminal.