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16. Abstract

This study addressed the problem of bridge ends on primary roads that are near intersecting roads. At these sites, standard guardrail treatments for the bridge end cannot be used because of insufficient run-out length and, therefore, alternate treatments are needed. The study approach consisted of (a) a survey of typical sites to identify the nature of the problem, (b) design of preliminary short radius guardrail treatments (c) a benefit/cost analysis of available systems, plus proposed new short radius guardrail treatments that could potentially be used at these sites, (d) development and crash testing of a short radius guardrail treatment, and (e) identification of recommended solutions to the problem for various types of roadways. From the survey, key design parameters were identified. In the preliminary design phase, three short radius guardrail treatments were detailed, consisting of two 60 mph designs and a 45 mph design. One of the 60 mph designs used the standard W-beam and the other used the thrie beam. The 45 mph design used nested W-beams. The B/C analysis was applied to evaluate various safety treatment options in terms of site conditions and roadway type. From this analysis, recommended use guidelines for the various options were developed.

A 60 mph short radius W-beam treatment was selected for further evaluation and development through full-scale crash testing. A nested W-beam system successfully passed all but one of the four tests selected as design impact conditions. In the failed test, a 4,500 lb vehicle impacting the center of the curved portion of rail at approximately 60 mph and 25 deg, rode under the guardrail. A new research project has been approved to test a 60 mph thrie-beam system which, it is believed, will satisfy all design impact conditions.

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BRIDGE RAILING END TREATMENTS AT INTERSECTING STREETS AND DRIVES

by

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Roger P. Bligh
and
Christopher Boyd Parnell

Research Report 1263-1
Research Study No. 2-5-91-1263
Bridge Railing End Treatment at Intersecting Streets and Drives

Sponsored by the

Texas Department of Transportation

in cooperation with the

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Texas Transportation Institute
The Texas A&M University System
College Station, Texas 77843-3135

November 1992

METRIC (SI*) CONVERSION FACTORS

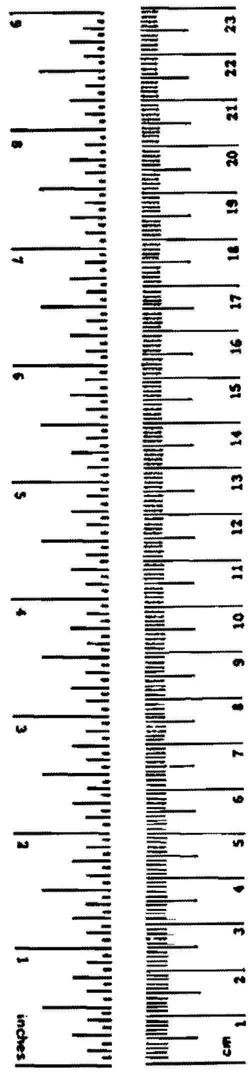
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	centimetres squared	cm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

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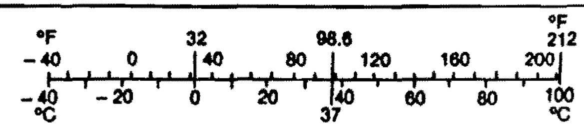

These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

ABSTRACT

This study addressed the problem of bridge ends on primary roads that are near intersecting roads. At these sites, standard guardrail treatments for the bridge end cannot be used because of insufficient run-out length and, therefore, alternate treatments are needed. The study approach consisted of (a) a survey of typical sites to identify the nature of the problem, (b) design of preliminary short radius guardrail treatments (c) a benefit/cost analysis of available systems, plus proposed new short radius guardrail treatments that could potentially be used at these sites, (d) development and crash testing of a short radius guardrail treatment, and (e) identification of recommended solutions to the problem for various types of roadways. From the survey, key design parameters were identified. In the preliminary design phase, three short radius guardrail treatments were detailed, consisting of two 60 mph designs and a 45 mph design. One of the 60 mph designs used the standard W-beam and the other used the thrie beam. The 45 mph design used nested W-beams. The B/C analysis was applied to evaluate various safety treatment options in terms of site conditions and roadway type. From this analysis, recommended use guidelines for the various options were developed.

A 60 mph short radius W-beam treatment was selected for further evaluation and development through full-scale crash testing. A nested W-beam system successfully passed all but one of the four tests selected as design impact conditions. In the failed test, a 4,500 lb vehicle impacting the center of the curved portion of rail at approximately 60 mph and 25 deg, rode under the guardrail. A new research project has been approved to test a 60 mph thrie-beam system which, it is believed, will satisfy all design impact conditions.

IMPLEMENTATION STATEMENT

Results of the study indicated that performance of the 60 mph short radius, nested W-beam treatment could be enhanced by use of a curved thrie beam in lieu of the nested W-beams. It is also expected that a thrie beam system would pose fewer installation problems. For these reasons, a new research project has been approved to further develop and test a 60 mph thrie-beam system. Consequently, implementation of the 60 mph short radius, nested W-beam treatment developed under this study is not recommended at this time.

KEY WORDS

Guardrail, Short Radius, Bridge, End, Intersecting, Roadway, Benefit/Cost, Crash Test, Safety, Treatment

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DISCLAIMER

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I. INTRODUCTION AND OBJECTIVES

A rigid barrier or railing is typically erected on either side of a bridge to prevent vehicles from leaving the travelway. Since the end of this railing is a hazard to motorists, it is usually shielded by a length of approach guardrail. The approach rail is usually relatively long since it is intended not only to prevent vehicles from striking the end of the railing, but also to prevent vehicles from entering the hazard that the bridge is spanning. According to the Texas Department of Transportation (TxDOT) standards, the length of the approach guardrail varies with roadway type and traffic volumes, but is usually at least 100 ft in length.

However, in some cases available space at the end of a bridge will not accommodate the standard length of approach guardrail. For example, in south Texas, crop irrigation is typically accomplished through a network of canals. Access to these canals and adjacent farms is usually provided by dirt roads that run parallel to the canals on one or both sides. Since access roads serving the canal typically intersect the main roadway a short distance from the bridge end, standard lengths of guardrail are not possible, as it would restrict access to the service road. Standards lengths of guardrail are also not possible in urban areas where streets and parking areas intersect the main roadway near the bridge end. In these cases, the bridge end is usually shielded by a short length of approach guardrail that is either terminated at the access road or curved and terminated along the access road, as shown in Figure I-1.

The objective of the study was to evaluate existing designs that could potentially be used to shield bridge ends near intersecting roadways, and to develop and test a new treatment if warranted. Candidate designs considered included crash cushions, commercially available bridge end treatments, shortened tangent sections of guardrail with selected end treatments, and short radius curved guardrail systems. Of these, it was felt that the curved guardrail systems offered the better solution for most of the problem sites, especially those with severe space restrictions.

Except for FHWA Technical Advisory No. T 5040.32, dated April 13, 1992, there are no state or nationally recognized standards for short radius guardrail treatments. The current practice in Texas is to curve the approach rail down the intersecting or secondary road, with the rail supported by standard wooden or steel posts typically spaced at 6 ft-3 in. throughout the radius. These standard posts are mounted in the soil and possess no breakaway features. As a result, a vehicle impacting at an angle in the radius could be decelerated rapidly, possibly

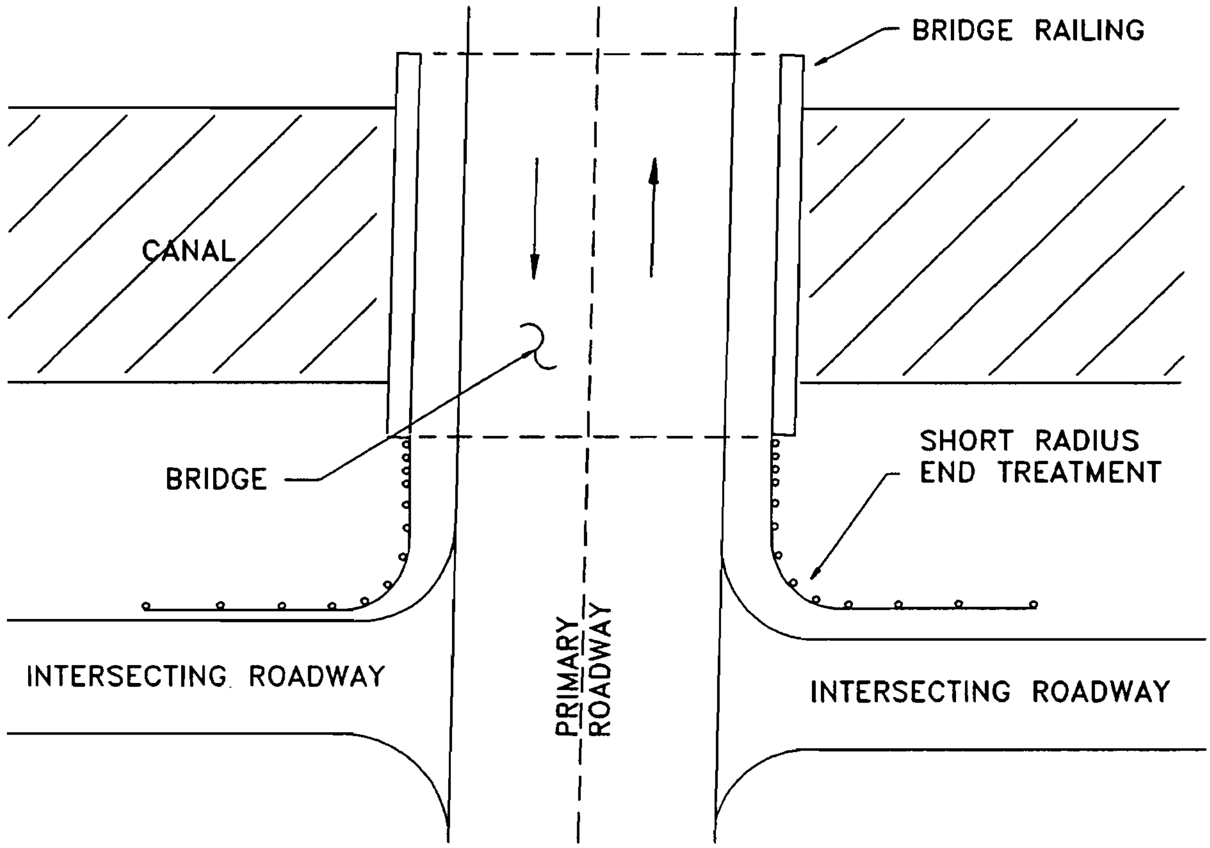


FIGURE I-1. Situation in Which Runout Length Is Restricted Along Primary Roadway

deflecting the posts supporting the rail enough to "ramp" the vehicle over the system. Additionally, the relatively short length of the system parallel to the roadway may not provide enough redirective strength to prevent a vehicle from contacting the rigid bridge end in a redirective type impact.

Test and evaluation of a low speed short radius guardrail treatment was conducted by the Southwest Research Institute for the Public Works Department at Yuma, Arizona (1). The short radius system developed in that study extended approximately 16 ft along the primary roadway and 18 ft down the intersecting roadway and was composed of steel W-beam. It performed satisfactorily during testing at impact speeds of 45 to 50 mph. Since a goal of the present study was the development of a 60 mph short radius system, the Yuma County system was not applicable.

In another study by the Southwest Research Institute, a 60 mph short radius guardrail treatment was developed for the Federal Highway Administration (FHWA) and the Washington Department of Transportation(2). As shown in Figure I-2, the system consisted of a steel W-beam guardrail curved at a radius of 8 ft-6 in., with a modified breakaway cable terminal (BCT) anchoring the system. Weakened rectangular wood posts were spaced at 6 ft-3 in. along the curved portion of the rail with the portion of the system adjacent to the main roadway angled towards the road at a 10 to 1 slope. The system was reported to have performed acceptably during the crash tests performed. However, it should be noted that the transition section shown in Figure I-2 was only designed for a 15 deg, multiple service level 1 (MSL-1) impact as defined in NCHRP Report 230 (5). Several transition designs capable of redirecting a 4,500 lb car impacting at 60 mph and 25 deg were subsequently developed for use with this system.

While the FHWA system represents a potential solution at certain sites, it was concluded that further development was needed for the types of site conditions under consideration in Texas. Specifically, it was considered desirable to develop a treatment that would further reduce or minimize vehicular penetration. Further, it was concluded that the transition between the guardrail and bridge rail has to be considered an integral part of a curved guardrail treatment. As such, the transition must be included in the design and testing of the overall system. There was also a need to develop a system that utilized round wood posts and other standard TxDOT guardrail hardware to the greatest extent possible.

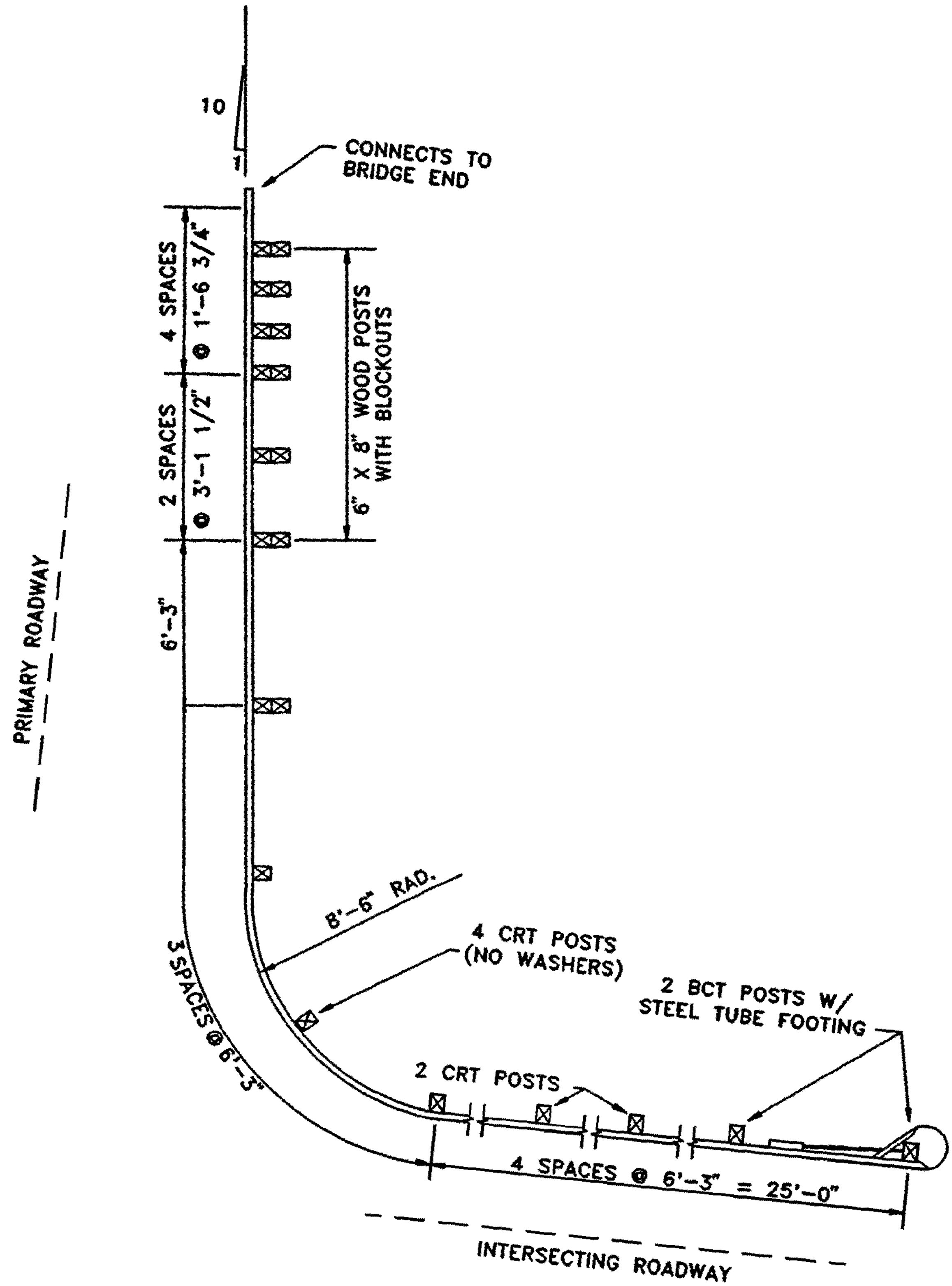


FIGURE I-2. Proposed FHWA Short Radius Guardrail Treatment

II. RESEARCH APPROACH

In the initial phase of the study, a field survey was made in south Texas, in cooperation with District 21 of the TxDOT, to investigate sites where bridge railings terminated near intersecting roadways. The purpose of the survey was to gather geometrical data on typical problem sites, data to be used in the evaluation of candidate treatments and in the design of a new treatment. Results of the survey are summarized in Appendix D. Information recorded included roadway types, speed limits, offset of bridge ends from the roadway, and typical clearances between the bridge ends and intersecting roads. Most sites where the short radius end treatment could be implemented were located on rural collector or rural arterial type roadways with speed limits of 55 mph. A smaller percentage was located on urban collector and arterial type roadways. Traffic volumes varied from as low as 400 ADT in rural areas to more than 6,000 ADT in more urbanized areas. The distance separating the bridge end from the edge of the travelway varied widely with roadway type, ranging from no separation to 13 ft. The distance from the bridge end to the intersecting road varied, but it was concluded that a treatment having a longitudinal length (in direction parallel to primary road) of 35 ft or less would fit most sites.

Following the survey, the research consisted of the following phases;

(a) Design of preliminary curved guardrail systems - This consisted of the design of curved guardrail systems, using the Barrier VII program (3) as the primary design tool. A description of this phase of the study is given in Chapter III.

(b) Evaluation of candidate systems by benefit/cost analysis - All potential treatments, including existing systems and well as those developed in part (a), were evaluated using a benefit/cost analysis program developed at the Texas Transportation Institute (TTI) (4). A description of this phase of the study is given in Chapter IV.

(c) Selection and testing of curved guardrail system - Based on the results of parts (a) and (b), a curved guardrail design was selected for further evaluation by crash testing. A description of this phase of the study is given in Chapter V.

(d) Development of conclusions and recommendations - Upon completion of part (c), a final evaluation of candidate treatments was made in developing conclusions and recommendations, as given in Chapters VI and VII.

III. PRELIMINARY SHORT RADIUS END TREATMENT DESIGNS

Prior to conducting the benefit/cost analysis, it was concluded that preliminary short radius guardrail designs should be developed which had the potential of meeting the needs of typical sites in Texas. These preliminary designs could then be included in the benefit/cost analysis as possible alternatives. It was agreed that the design(s) should preferably have the following characteristics:

(1) The system should be simple to install and maintain and should utilize TxDOT standard guardrail hardware;

(2) The system should be cost effective when compared to other options, including commercially available systems;

(3) The system should safely contain and/or redirect the 1,800 lb and 4,500 lb design vehicles when impacting at 60 mph at an angle in curved section without excessive deflections or decelerations; and

(4) The transition should be designed as an integral part of the system and have sufficient strength to redirect a 4,500 lb passenger car impacting at 60 mph and 25 deg.

3.1 Design Elements

A short radius guardrail end treatment consists of two basic elements. The curved portion of the system is intended primarily to capture and contain errant vehicles and, according to NCHRP Report 230 (5), must be able to safely decelerate the 1,800 lb and 4,500 lb design vehicles. However, the transition performs a different function. The transition of the system is intended to connect the rigid bridge end to the more flexible W-beam of the curved section and must be sufficiently strong to redirect the 4,500 lb design vehicle. Therefore, development of the system consisted of three tasks: design of the radius, design of the transition region, and design of the system as a whole considering interaction of the two elements.

Stiffness of the curved region decreases as the radius increases, thus reducing impact forces. However, rail deflection will increase with decreasing stiffness. Also, as the radius becomes larger, the number of sites which can accommodate the system decreases. Thus, the goal was to develop a minimum radius system that would satisfy NCHRP Report 230 evaluation criteria for 60 mph impacts.

The transition must be strong enough to redirect a vehicle while preventing excessive pocketing or snagging of the vehicle with the transition or with the bridge end. Also, it was desirable that the length of the transition in the short radius treatment be as short as possible.

3.2 Evaluation and use of Barrier VII as a Design Tool

The first step in the design process was to examine the capabilities of the Barrier VII computer program (3) with regard to simulation of vehicular impacts with a curved guardrail system. Barrier VII was to be the primary tool in the initial design of the system. Other than the previously mentioned studies by Southwest Research Institute (1,2), Barrier VII has been used primarily to study redirective vehicular impacts on straight portions of longitudinal barriers. Little has been done to validate BARRIER VII capabilities with regard to the simulation of vehicular impacts with short radius end treatments.

The limited study indicated that Barrier VII tended to overpredict the severity of an impact into the curved part of the short radius system. When compared to actual crash test data, Barrier VII generally predicted smaller system deflections and greater vehicle decelerations. Given this trend, Barrier VII was used in the project as a design tool to complement the design process. Results of the validation effort are given in Appendix A.

3.3 Design Impact Conditions

In the absence of definitive test guidelines for short radius curved guardrail treatments, three sets of design impact conditions were selected. They were selected within general guidelines given in NCHRP Report 230 (5) in regard to design vehicles, impact speeds, and impact angles for conventional barrier elements. An attempt was made to select "worst case" conditions. The design impact conditions included (a) angled impacts into in the curved section with both the 1,800 lb and the 4,500 lb design vehicles, (b) an impact in the curved portion with the 4,500 lb vehicle approaching parallel to the normal direction of traffic on the primary road, and (c) an angled impact in the transition region with the 4,500 lb design vehicle. For impact conditions (a), the two 60 mph angled impacts were near the center of the curved portion, one with the 1,800 lb vehicle at 20 deg and the other with the 4,500 lb vehicle at 25 deg. Impact angle is the angle between the normal direction of traffic on the primary road and the approach path of the impacting vehicle. For impact condition (b), the centerline of the vehicle was aligned with the centerline of that portion of the rail parallel to the primary road. When aligned in this manner, initial vehicular contact was in the curved section of the treatment. The purpose of this design impact was to insure that the vehicle did not penetrate into the more rigid transition region. For impact condition (c), the vehicle impact speed was 60 mph and the impact angle was 25 deg. The initial or critical impact point of the vehicle with the transition was selected by use of Barrier VII, using a procedure developed at TTI (14). Critical impact point is that judged to have the greatest potential for causing snagging or pocketing of the vehicle with barrier elements or with the end of the bridge railing or parapet.

3.4 Design Process

Design of preliminary short radius guardrail treatments consisted of an iterative process. Initially a specific design was selected based on previous research and the collective judgement of the researchers. The design was then evaluated by the Barrier VII program for the design impact conditions described in the previous section. Modifications were then made as deemed necessary and the modified design was evaluated by Barrier VII for the design impact conditions. This process was repeated until acceptable performance was predicted.

Three preliminary short radius designs were developed by this process. The first two were designed for impact speed up to 60 mph, and the third was designed for impact speeds up to 45 mph.

3.4.1 Design of 60 mph Short Radius Treatments

The first of the two 60 mph short radius guardrail treatment designed by the above procedure is illustrated in Figure III-1. It consists of two straight segments of guardrail connected by a curved section having a radius of 14 ft-3 in. It extends 31 ft-5 1/4 in. parallel to the primary road and 60 ft-8 in. along the intersecting road. The guardrail is terminated by a standard TxDOT turndown W-beam rail along the intersecting road.

With the exception of the transition and turndown sections, the system is composed of 12 gauge W-beam elements supported at 6 ft-3 in. intervals by several types of wooden posts. Outside the curved area, standard TxDOT 7-in. diameter wood posts, embedded 38 in., are used. Within the curved area, 7-in. diameter wood posts, weakened by holes at the ground line and 16 in. below the ground line, are used to facilitate fracture during impact. A similar

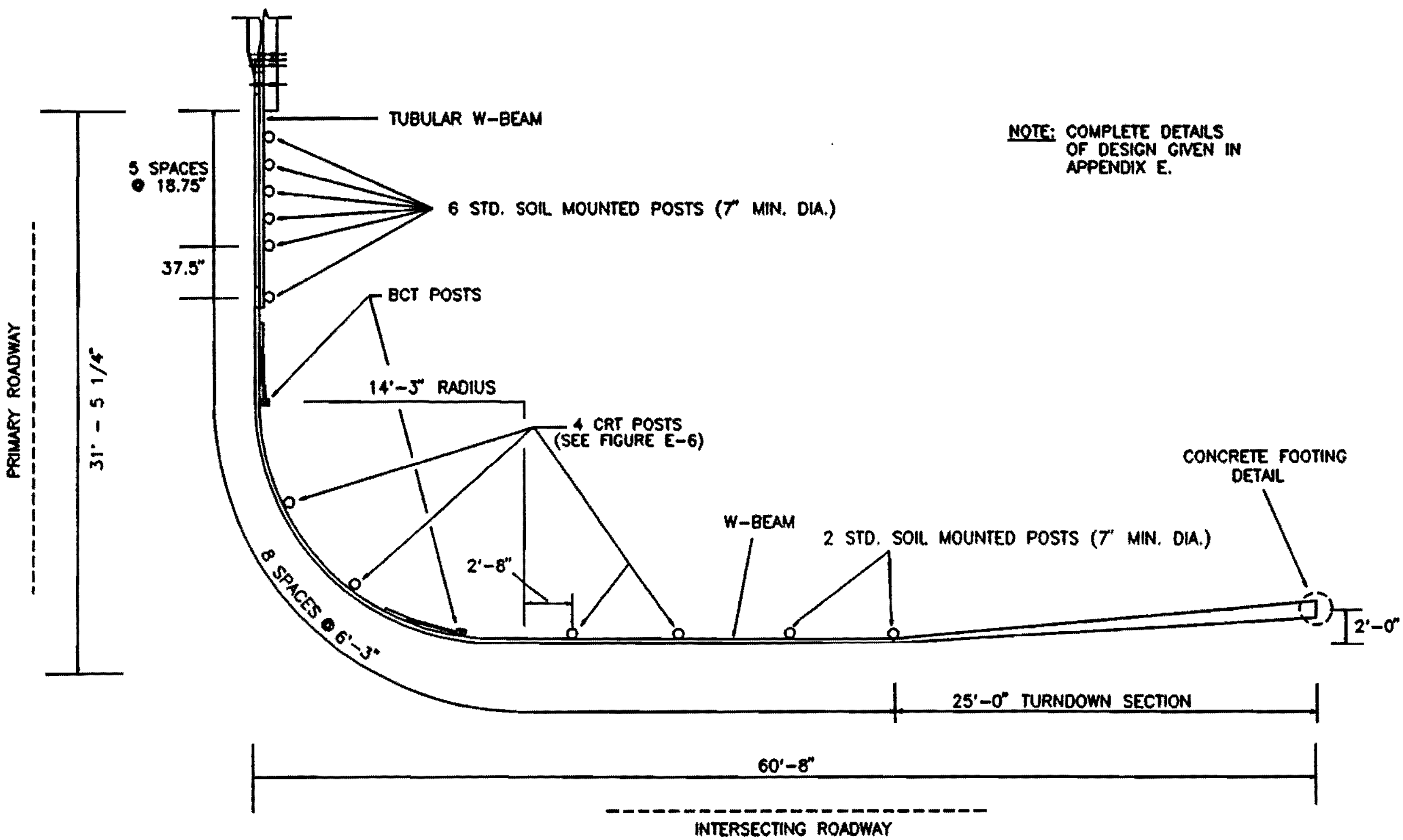


FIGURE III-1. Proposed 60 mph W-Beam Short Radius Treatment weakening mechanism has been used by others for guardrail end treatments (15). Also, two BCT (breakaway cable terminal) anchors are used, one at the upstream end of the transition and one in the curved region. The one at the upstream end of the transition is used to facilitate redirection of a vehicle impacting in the transition section and the one in the curved region is used to facilitate redirection of a vehicle impacting at a shallow angle in the curved section. The BCT post is a specially anchored rectangular wooden post with a cable attached to the post near the ground line. This cable is connected to the downstream rail to transfer the force in the rail to the base of the post.

To strengthen the transition region, the system uses a 12 ft-6 in. tubular W-beam supported by standard TxDOT wooden posts spaced at 1 ft-6 3/4 in. near the bridge end. The tubular W-beam, shown in Figure III-2, consists of two pieces of W-beam welded together back-to-back to form a "tube" which has a relatively large resistance to bending.

Appendix A contains a description of the predicted performance of the design of Figure III-1 as determined by Barrier VII for the design impact conditions. As discussed subsequently, this design was selected for further development and analysis through a crash test program. The system of Figure III-1 was modified several times as the crash test program progressed.

The second 60 mph short radius guardrail treatment designed by the above procedure is illustrated in Figure III-3. It consists of two straight segments of guardrail connected by a curved section having a radius of 14 ft-3 in. It extends 28 ft-3 3/4 in. parallel to the primary road and 51 ft-9 in. along the intersecting road. The guardrail is terminated by a 12.5 ft turndown thrie beam rail along the intersecting road.

With the exception of the transition and turndown sections, the system is composed of 10 gauge thrie beam elements supported at 6 ft-3 in. intervals by several types of wooden posts. Outside the curved area, standard TxDOT 7-in. diameter wood posts, embedded 38 in., are used. Within the curved area, 7-in. diameter wood posts, weakened by holes at the ground line and 16 in. below the ground line, are used to facilitate fracture during impact. To strengthen the transition region, the system uses nested 10 gauge thrie beam elements supported by standard TxDOT wooden posts spaced at 1 ft-6 3/4 in. near the bridge end.

Barrier VII simulations of impacts with the thrie beam system predicted occupant risk values slightly in excess of recommended limiting values as given in NCHRP Report 230 (5). Although Barrier VII predicted the thrie beam systems would not meet all recommended impact

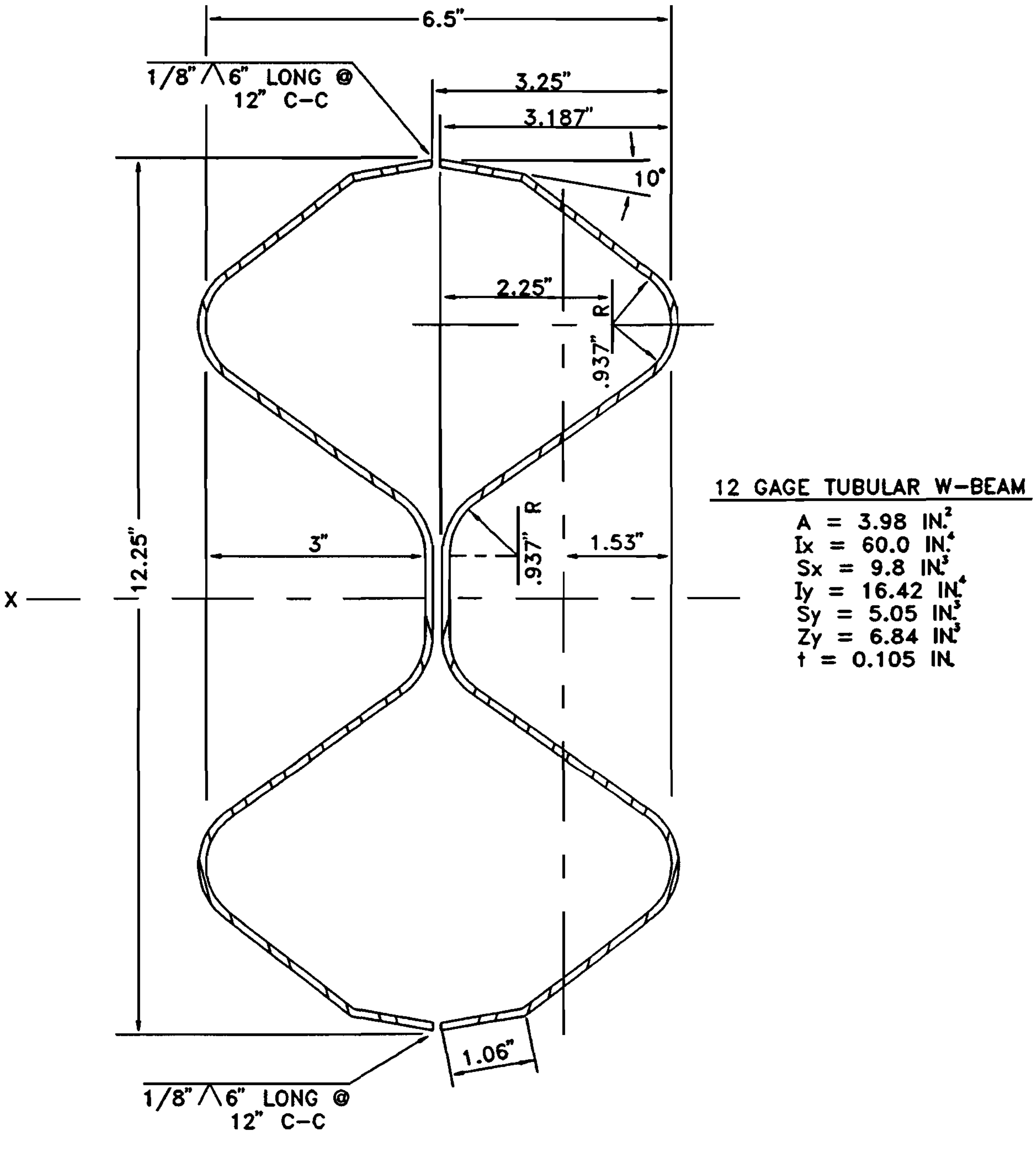


FIGURE III-2. Cross Section of Tubular W-Beam

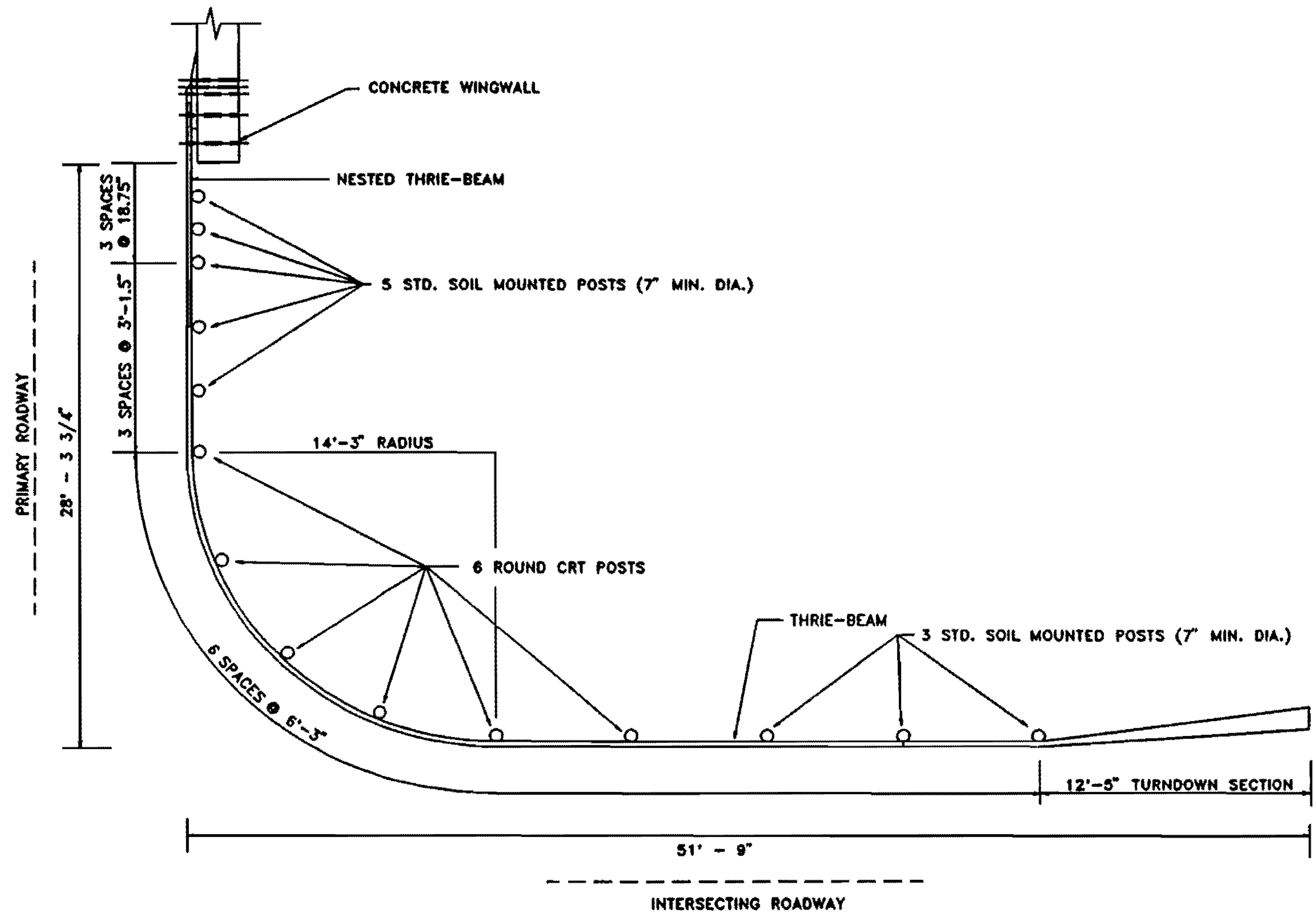


FIGURE III-3. Proposed 60 mph Short Radius Guardrail Treatment with Thrie-Beam

performance criteria, it was included as an option in the benefit/cost analysis since it had unique cost and performance characteristics, and the possibility existed that the system would prove to be cost beneficial for certain roadway types and traffic volumes.

3.4.2 Design of a 45 mph Short Radius Treatment

In addition to the two 60 mph designs, it was concluded that a lower service level design could potentially be cost beneficial, at least for the lower speed and/or volume roads. The preliminary 45 mph short radius design, as determined by the previously described process, is illustrated in Figure III-4. It extends 18 ft-3 in. parallel to the primary road and 37 ft-0 in. along the intersecting roadway. With the exception of the turndown, the system was composed of nested W-beam guardrail supported at 6 ft-3 in. intervals by both standard and breakaway 7-in. diameter wood posts. The 45 mph transition near the bridge end was composed of nested W-beam supported by standard wood posts. Design impact conditions were the same as those used for the 60 mph design except the impact speed was reduced to 45 mph. As can be seen, dimensions of the 45 mph system were considerable smaller than the 60 mph system since the kinetic energy of a vehicle travelling at 45 mph is approximately one-half that at 60 mph.

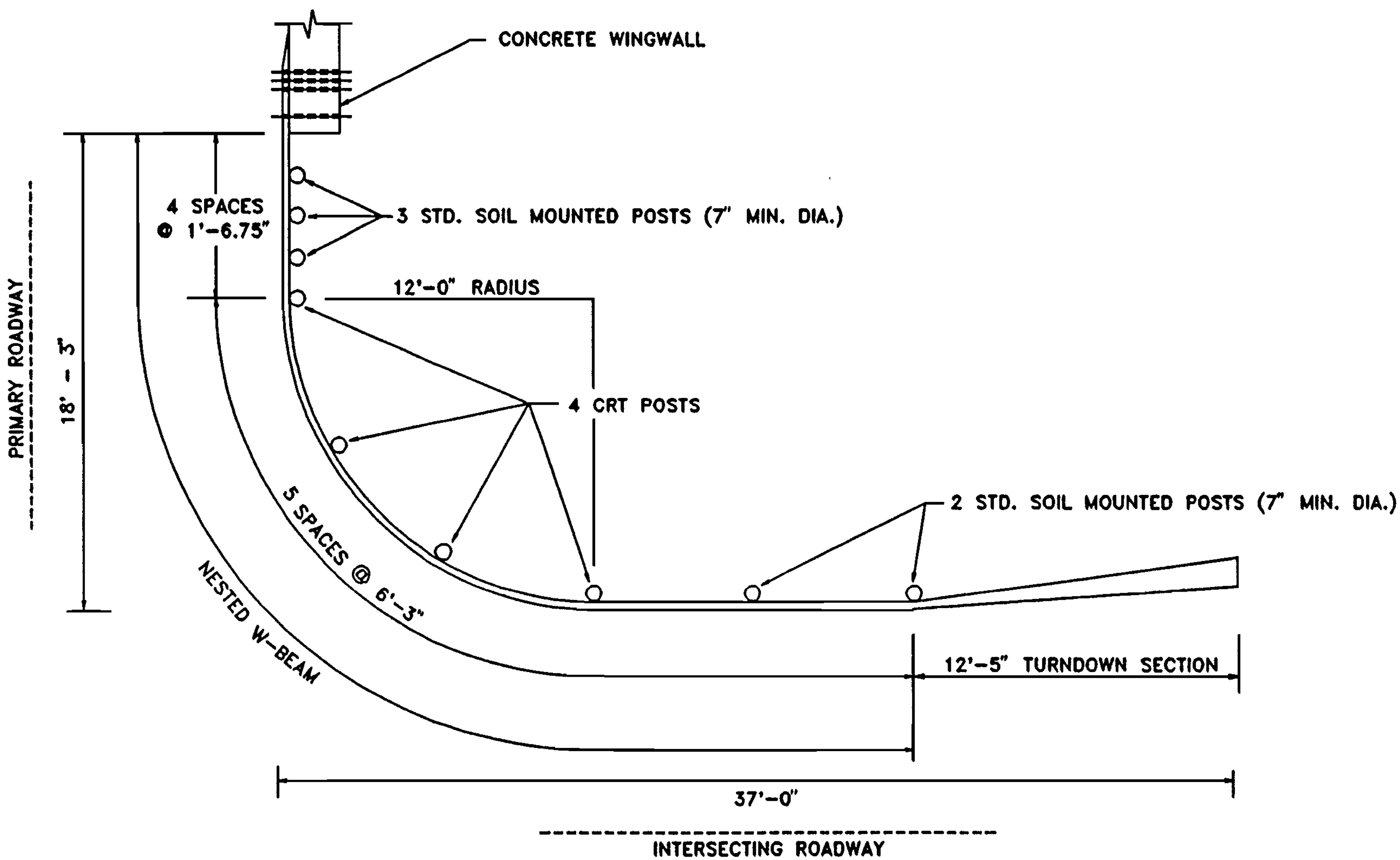


FIGURE III-4. Proposed 45 mph Nested W-Beam Short Radius Treatment

IV. BENEFIT-COST ANALYSIS

A benefit-cost (B/C) analysis was made to evaluate various options, including the short radius end treatments. The B/C program used in the analysis was developed at TTI (4), and is based on the premise that on each type of roadway, a certain percentage of vehicles will inadvertently leave the travelway. Of these, a certain percentage will get far enough off the travelway to impact a roadside hazard. The program estimates and compares benefits (as measured by reductions in accident or societal costs) with direct costs associated with each roadside safety alternative.

To predict the number of annual accidents, the B/C program utilizes a probability-encroachment model. For each encroachment, vehicle trajectory is superimposed onto all of the alternatives being considered by the program. If the vehicle impacts a system, the speed, angle, and region of impact is noted, and the proper severity index curve is indexed to find the appropriate value. Societal and direct costs for all impacts are summed up on an annual basis to find the annual benefits and costs of each treatment.

Direct costs are those associated with the initial, maintenance, and accident repair costs of a safety treatment. To determine if an improvement is cost beneficial, the following formula is used:

$$BC_{2\text{-}1} = (SC_1 - SC_2)/(DC_2 - DC_1) \tag{1}$$

where

$BC_{2\text{-}1}$ = Benefit-Cost ratio of alternative 1 compared with alternative 2;
SC_1 = annualized societal cost of alternative 1;
DC_1 = annualized direct cost of alternative 1;
SC_2 = annualized societal cost of alternative 2; and
DC_2 = annualized direct cost of alternative 2.

Alternative 2 is normally considered to be an improvement relative to alternative 1.

4.1 Candidate Systems

For purpose of analysis, candidate systems were grouped in one of two categories. The first group were those that could be accommodated within a relatively short longitudinal clearance of approximately 35 ft, i.e., those that could be used if the distance from the bridge end to the intersecting road was approximately 35 ft. The second group included those that could be accommodated within an intermediate longitudinal clearance of approximately 62.5 ft. It is believed that most problem sites will fall within one of these two categories.

A total of eight safety treatments were evaluated in the benefit-cost analysis. Within the short clearance category, the following candidates were evaluated:

(1) The 45 mph short radius guardrail treatment, shown in Figure III-4.

(2) The 60 mph short radius guardrail treatment utilizing W-beam guardrail, shown in Figure III-1.

(3) The 60 mph short radius guardrail treatment utilizing thrie beam guardrail, shown in Figure III-3.

(4) The TREND, as marketed by Energy Absorption Systems, Inc. (6), shown in Figure IV-1.

(5) The sand tub inertia crash cushion (7), as shown in Figure IV-2.

Within the intermediate clearance category, the following candidates were evaluated:

(6) A 50 ft length of straight guardrail, including a 12.5 ft tubular transition, and a 12.5 ft turndown end treatment, as shown in Figure IV-3.

(7) A 62.5 ft length of straight guardrail, including a 12.5 ft tubular transition, and an ET-2000 end treatment, as shown in Figure IV-4.

(8) A 50 ft length of straight guardrail, including a 12.5 ft tubular transition, and a curved guardrail end treatment with a radius of 14.25 ft, as shown in Figure IV-5.

A ninth option included in the B/C analysis was the "do nothing" option, or the untreated bridge end option adjacent to a body of water, as illustrated in Figure IV-6.

4.2 Costs

To determine societal and direct costs, it was necessary to define values of various parameters for each candidate, including space requirements, impact performance and the corresponding severity indices, initial, repair, and maintenance costs, and the position of the system relative to the roadway. Geometrical layout and position relative to the road for each system were determined from known dimensions of each system and from the bridge end offset assumed for the B/C analysis (see Figure IV-6). Installed costs for the commercially available

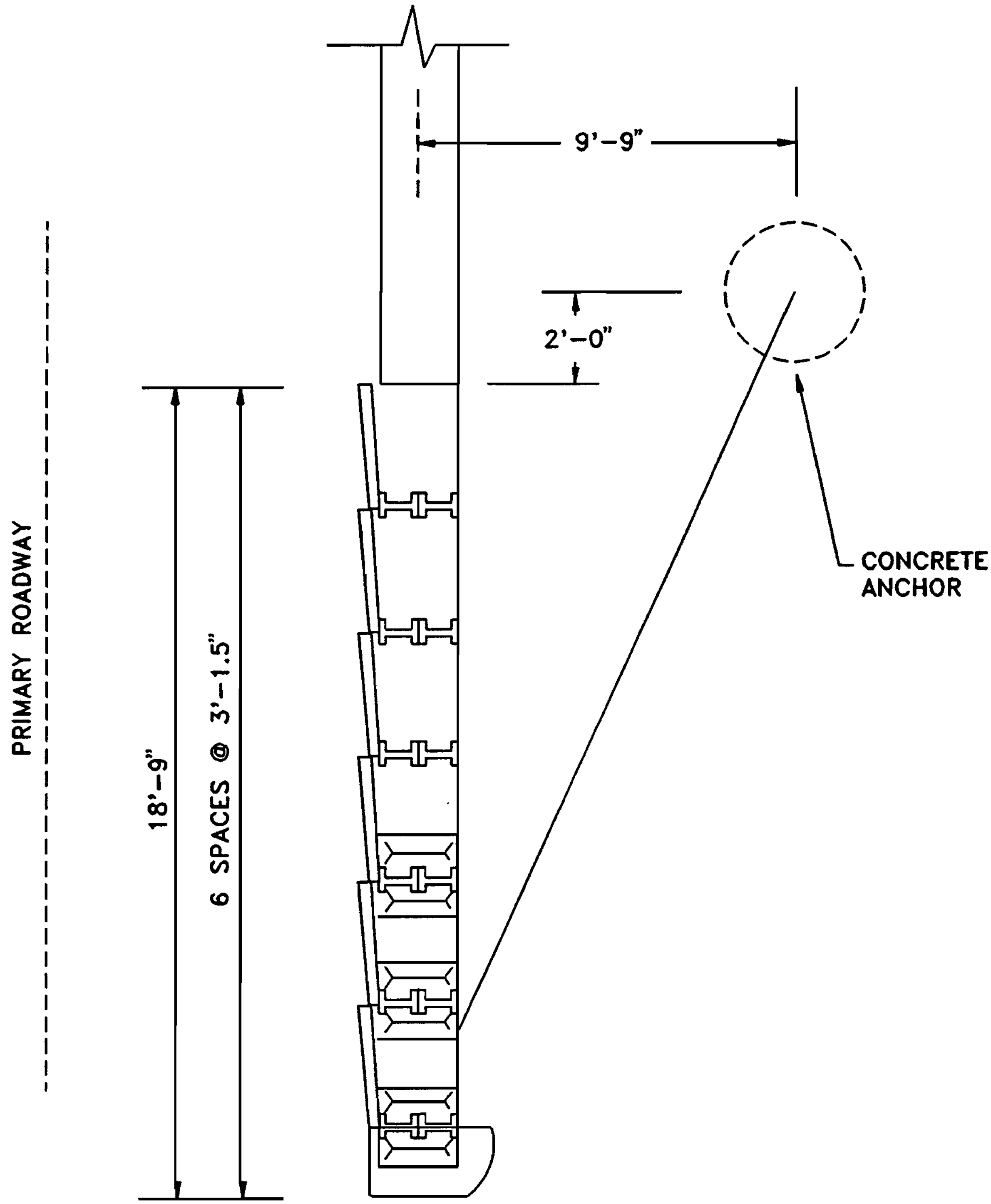


FIGURE IV-1. Design Parameters For TREND End Treatment

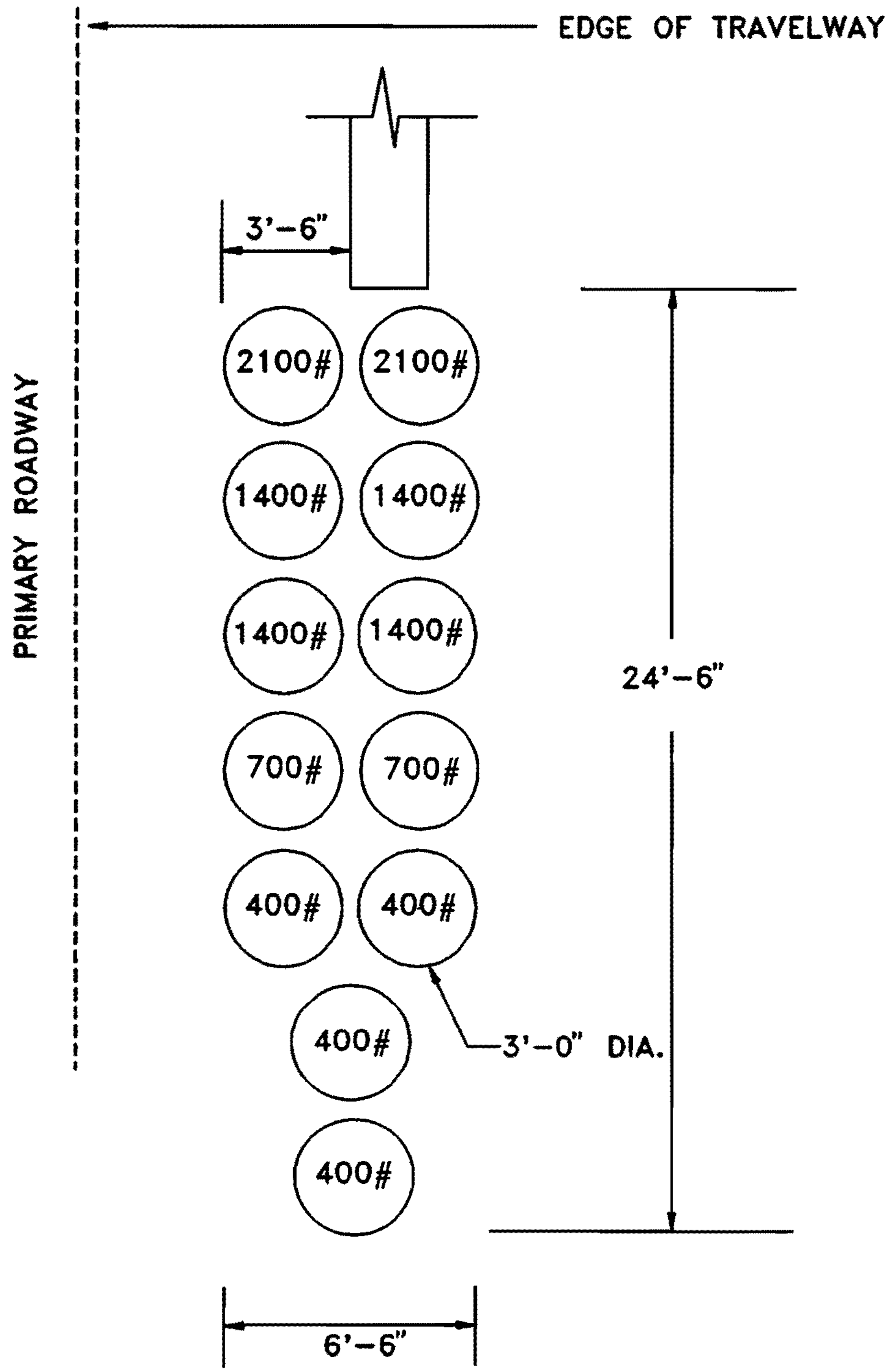


FIGURE IV-2. Design Parameters For 60 mph Sand Tub Crash Cushion

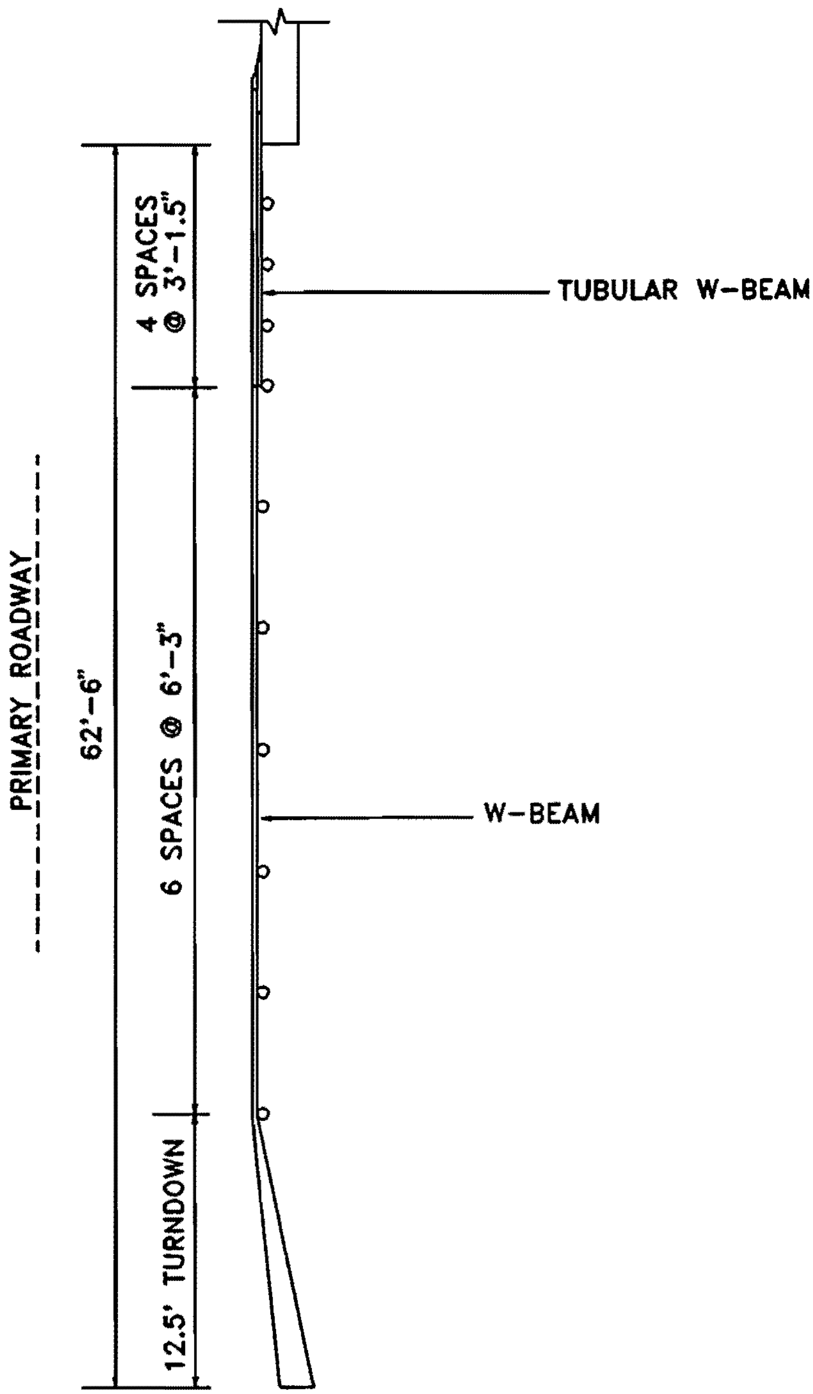


FIGURE IV-3. Design Parameters - 50 ft Rail Plus 12.5 ft Turndown

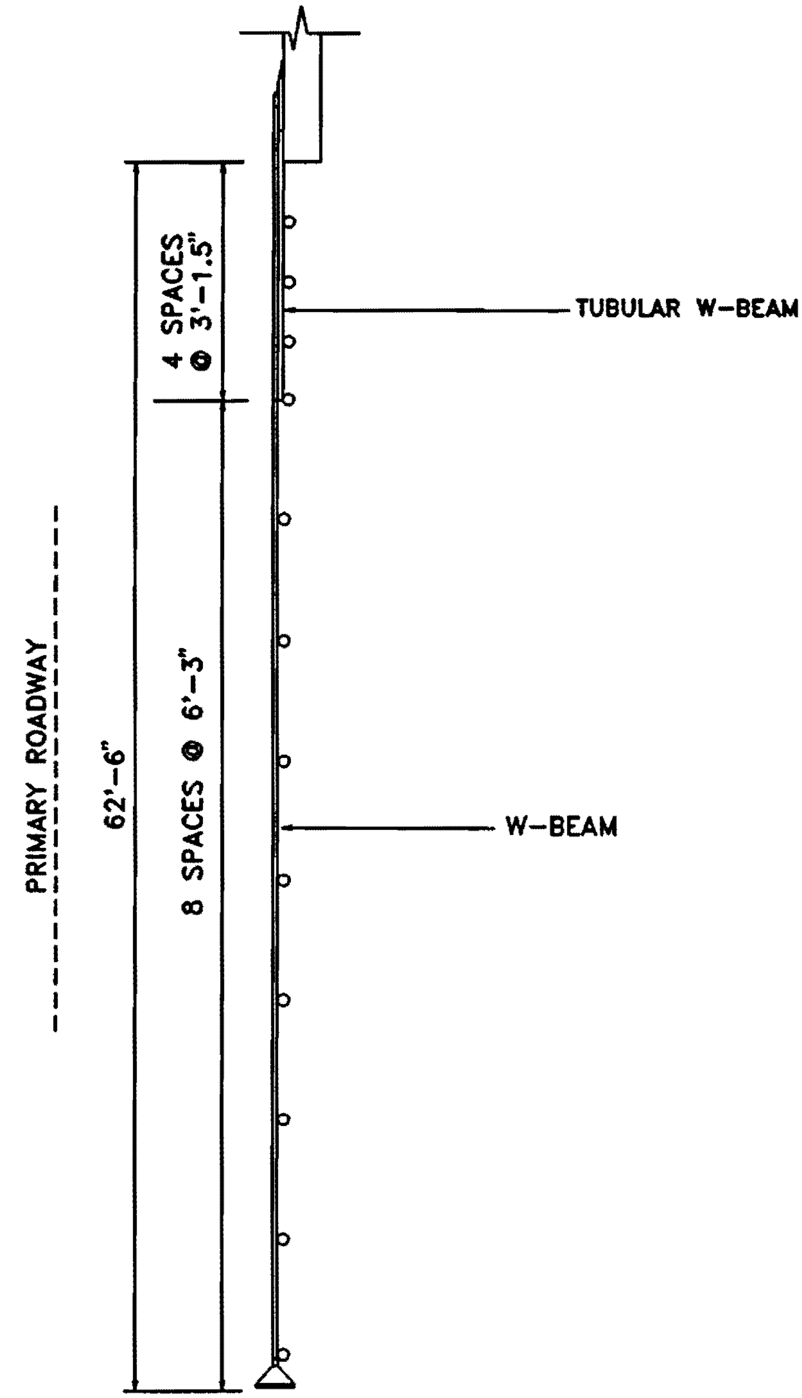


FIGURE IV-4. Design Parameters For ET-2000 End Treatment

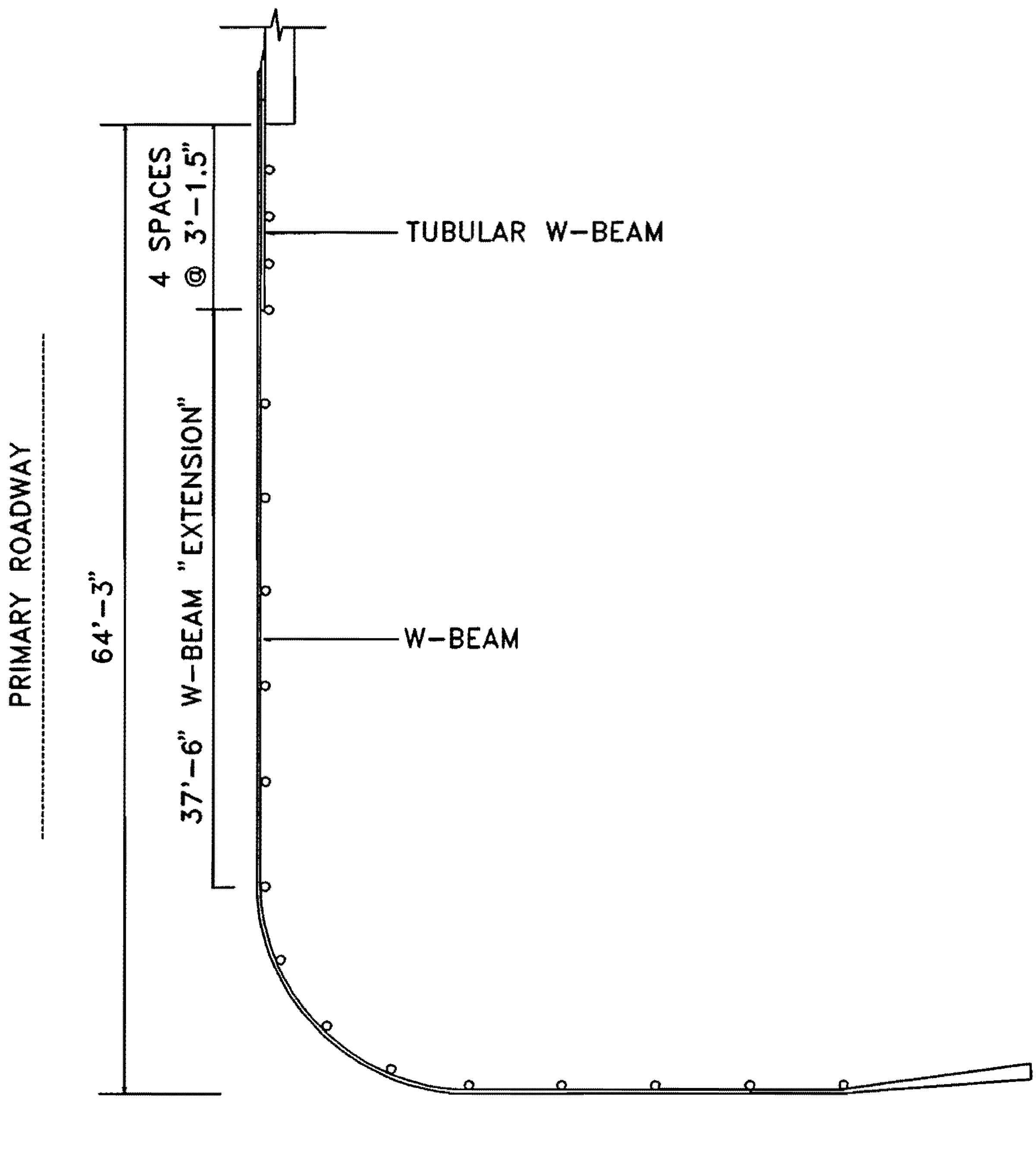


FIGURE IV-5. Design Parameters for Extended Short Radius W-Beam Treatment

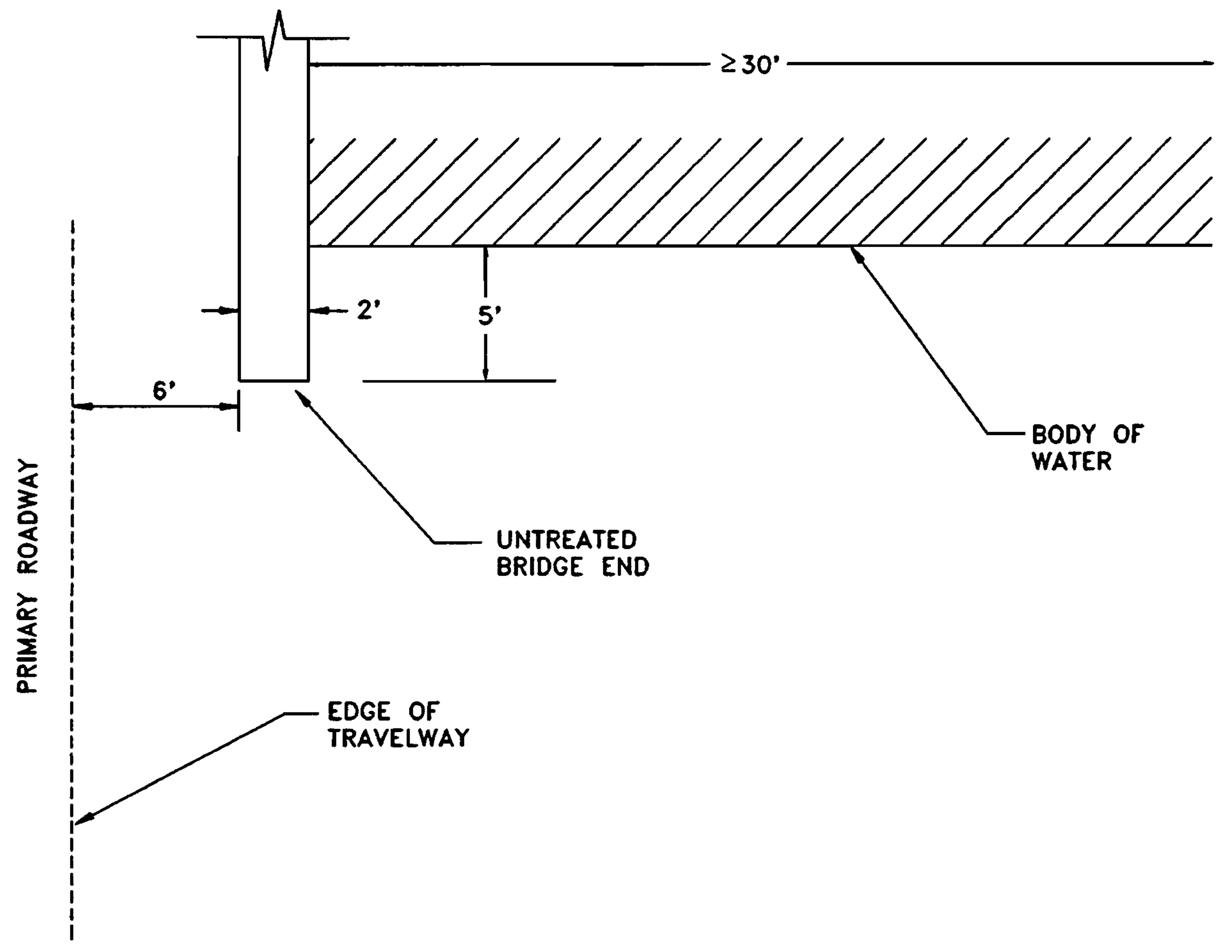


FIGURE IV-6. Assumed Parameters for Untreated Bridge End

systems were obtained from suppliers and/or bid prices provided by TxDOT. Estimated unit costs used in determining initial and repair costs of the non-commercial systems were as follows:

12 gauge W-beam	\$2.20/ft
12 gauge tubular W-beam	\$9.00/ft
Thrie beam	\$6.00/ft
7 in. diameter post	\$11.50/each
Labor for rail assembly	\$1.90/ft
Labor for post installation	\$9.90/post

Based on the aforementioned data, the estimated installed cost of each of the eight options were as follows:

Systems requiring short longitudinal clearance

(1) 45 mph Short Radius Nested W-Beam System	\$ 1000.00
(2) 60 mph Short Radius W-Beam System	\$ 1250.00
(3) 60 mph Short Radius Thrie Beam System	\$ 3500.00
(4) TREND	\$ 5000.00
(5) Sand Tubs	\$ 2400.00

Systems requiring intermediate longitudinal clearance

(6) W-Beam Rail with Turndown	\$ 900.00
(7) W-Beam Rail with ET-2000	\$ 1500.00
(8) W-Beam Rail with Curved End Treatment	\$ 1750.00

The "do nothing" option was assumed to have no installed cost.

Following a procedure used in a previous TTI study (8), repair costs for each system that would result from predicted impacts were assumed to vary linearly with "Impact Severity" (IS) of the predicted impact. Repair costs also were dependent on the region of each respective system at which the impact was predicted to occur. For example, repair costs for an impact in the curved region of a short radius guardrail treatment were different from those for an impact in the transition region. For the non-commercial systems, the Barrier VII program provided an estimate of system damage for impacts at different regions of the system, which could then be correlated with the IS of the impact. Impact repair costs for the commercial systems were estimated from damage data reported during full-scale crash tests for various impact conditions (vehicle mass, impact speed, impact angle, and impact location). IS has units of lb-ft and is defined as follows:

$$IS = \tfrac{1}{2}M(V \, \mathrm{Sin}\Theta)^2$$

where M = vehicle mass,

V = impact speed, and

Θ = impact angle.

For impacts into regions of the safety alternative that redirect the vehicle, Θ is the angle between the vehicle's approach path and the direction of traffic on the primary road. For impacts into regions of the safety alternative that decelerate the vehicle to a stop, $\mathrm{Sin}\Theta$ is set equal to 1.

To calculate repair costs of a given impact, the B/C program cross-indexes the impacting vehicle's IS with the repair cost vs. IS graph for the given system and the region of the system impacted. For a given system and a particular region of the system, two parameters are used to define the repair cost vs. IS graph: (1) the slope of the assumed repair cost vs. IS graph, and (2) the value of IS at the intercept of the graph with the IS axis. These values are given on the fourth line of the input for each sub-data set; the slope is the first entry and the intercept is the second entry. A listing of input data for each of the eight safety options and the "do nothing" option is given in Appendix B. For example, for option 1 (45 mph Short Radius Nested W-Beam System) (see Section 4.1), the slope of the repair cost vs. IS graph for the middle part of the curved section (noted as "LENGTH OF RAIL BETWEEN MIDDLE POSTS IN CURVE in the input listing of Appendix B) was estimated to be 0.001 \$/IS. The intercept of the graph with the IS axis was assumed to equal zero, i.e., the graph passes through the origin of the axes. It was assumed that a vehicle will be decelerated to a stop for impacts in this region. Thus, for example, if this region were impacted by a 4,500 lb vehicle traveling at 30 mph (impact angle assumed to have negligible effect on damage or repair costs, and thus $\mathrm{Sin}\Theta$ set equal to one), the IS would equal 135,000 lb-ft, and the repair cost would equal

$$135{,}000 \times 0.001 = \$135.$$

For each option, it was assumed that the repair costs would never exceed the installed cost of the system.

Routine maintenance costs of each option was assumed negligible. Although each system will require varying degrees of upkeep, it is believed costs associated therewith will not significantly alter the B/C analysis.

4.3 Determination of Severity Indices

A severity index must be assigned to each impact predicted to occur by the B/C program. Societal or accident costs are then defined in terms of the index using data given in reference 9. To define the severity index a safety treatment or unprotected hazard is divided into distinct regions, each of which performs in a particular manner when impacted at various angles and speeds. For example, three regions were used for the untreated bridge end or "do-nothing" option. These were (1) the exposed bridge abutment or bridge rail end (referred to as "Hazard #1" in Figure B-57 of Appendix B), (2) the bridge rail itself (referred to as "Hazard #2" in Figure B-58 of Appendix B), and (3) an assumed water hazard (referred to as "Hazard #3" in Figure B-59 of Appendix B). For example, these curves indicate that the severity of a high speed impact at 5 deg into the railing itself would be relatively small in comparison to the same impact into the end of the unshielded bridge end.

For each region, a family of severity index versus impact speed curves were constructed for a range of impact angles. Based on studies at TTI (8), severity indices were estimated from occupant risk values (occupant impact velocity and ridedown acceleration) obtained from Barrier VII simulations and/or published crash test data. Severity index curves for each region of each of the nine options were developed for impacts at 5, 15, 25, 35, and 45 deg. For example, to construct the severity index curves for an 1,800 lb vehicle impacting the side of a bridge rail (see Figure B-58 of Appendix B) Barrier VII simulations were first made with an 1,800 lb vehicle at a 5 deg impact angle at speeds of approximately 30, 45, and 60 mph. These runs yielded three data points from which the severity index curve for the 5 deg impact angle were obtained. This process was repeated for angles of 15, 25, 35, and 45 deg for both the 1,800 and 4,500 lb vehicles. It was assumed that the severity index curves for vehicles weighing more than 4,500 lb would equal those of the 4,500 lb vehicle. This is believed to be a conservative assumption since it will generally result in an overstatement of impact severity for the heavy vehicles. However, the net effect of this assumption on the B/C analysis will be small since heavy vehicles were assumed to constitute only a small percentage of the vehicle mix.

In most cases, severity index data points resulted in curves that were linear. However, the severity of striking certain hazards (such as a guardrail turndown) varied considerably with speed, and in these cases, the slope of the severity curves varied with impact speed. Also, data points at differing angles were so close together for certain regions that more than one angle of impact was represented by a single line. This was especially the case for the more severe hazards, such as the untreated bridge end.

To obtain necessary values of occupant impact and ridedown deceleration for systems which could not be simulated by the Barrier VII program, published results of full-scale crash tests were used. Appropriate values for the ET-2000 (10), and TREND (6) were obtained in this manner. Occupant risk values for the sand tub crash cushion were obtained from another TTI study (8). The complete set of severity index curves for the nine options evaluated are given in Figures B-1 through B-59 of Appendix B.

4.4 Results of B/C Analysis

The B/C analysis was used to determine recommended safety treatments for three categories of site conditions. For each category, B/C ratios were determined for each relevant option when compared to the untreated bridge end or "do nothing" option for a given roadway type and varying volumes of traffic (as measured by ADT). By comparing the B/C ratios, the most cost beneficial option could be determined as a function of roadway type and traffic volume. Eight roadway types were included in the analysis:

(1) Rural two-lane collector;

(2) Rural four-lane collector;

(3) Urban two-lane collector;

(4) Urban four-lane collector;

(5) Rural two-lane arterial;

(6) Rural four-lane arterial;

(7) Urban two-lane arterial; and

(8) Urban four-lane arterial.

It is noted that within the B/C program, vehicular encroachment characteristics, as defined by joint distributions of speed and angle, are unique to each of the above roadway types (4).

Note that up to nine options were considered, consisting of an untreated bridge end option and eight safety treatment options as described in Section 4.1. A description of each of the three sub-analysis and results therefrom follows.

4.4.1 Most Cost Beneficial Options - Category I Sites

This part of the analysis is applicable at sites, referred to as Category I sites, that have adequate space, level shoulders and adjoining terrain, and a longitudinal clearance between the bridge end and the intersecting road of 35 ft, such that each of the five "short clearance" treatments (see Section 4.1) could be installed. For such sites, the analysis identified the most cost beneficial options as a function of traffic volume for various roadway types.

Results are summarized in Table IV-1. The analysis indicates that a safety treatment is cost beneficial on rural type roadways for ADT's in excess of approximately 100 and on arterial type roadways for ADT's in excess of approximately 200. As a general rule, rural roadways require safety treatment at lower ADT's than do urban roadways since speeds are generally higher on rural roads.

TABLE IV-1. Traffic Volume at Which Given Option Is Most Cost Beneficial - Category I Sites

Option	2-Lane Rural Collector	4-Lane Rural Collector	2-Lane Rural Arterial	4-Lane Rural Arterial	2-Lane Urban Collector	4-Lane Urban Collector	2-Lane Urban Arterial	4-Lane Urban Arterial
Do Nothing	<120	<150	<80	<100	<370	<480	<180	<220
45 mph Short Radius Nested W-Beam	≥120	≥150	≥80	≥100	≥370	≥480	≥180	≥220

Somewhat surprisingly, the 45 mph short radius nested W-beam system (Figure III-4) was found to be the most cost beneficial safety treatment for all roadway types for Category I sites. This occurs because the reduced cost and space requirements of this system offset its limited impact performance capabilities and consequently societal costs of accidents predicted to occur with the system. However, it was found that B/C ratios for the 60 mph short radius W-beam option (Figure III-1) were only about 15 percent lower than the 45 mph short radius treatment for rural arterial roads and about 20 percent lower for all other roadway types. Figure IV-7 shows the annualized societal cost versus ADT of these systems for a 2-lane rural collector. Since differences in societal costs were not large and since differences in direct costs of the two systems were not large, it follows that the B/C ratios would not differ greatly. A complete set of annualized societal costs versus ADT for each of the eight roadway types for the 45 mph and the 60 mph short radius treatments is given in Appendix C. As can be seen in the data of Appendix C, the annualized societal cost of the 60 mph design was actually lower than the 45 mph design for some ADT-roadway type combinations. Differences between B/C ratios of the two systems are within estimated accuracy ranges of the analysis methodology and input data used in the analysis. B/C ratios for the other three options were considerably lower than those of the short radius W-beam systems.

4.4.2 Most Cost Beneficial Options - Category II Sites

This part of the analysis is applicable at sites, referred to as Category II sites, that have adequate space, level shoulders and adjoining terrain, and a longitudinal clearance between the bridge end and the intersecting road of 65 ft or more, such that all eight treatments (see Section 4.1) could be installed. For such sites, the analysis identified the most cost beneficial options as a function of traffic volume for various roadway types.

Results are summarized in Table IV-2. Little differences are seen between Tables IV-1 and IV-2. However, the following was found:

(a) B/C ratios of the 62.5 ft length of straight guardrail with an ET-2000 end treatment (Figure IV-4), the 62.5 ft length of straight guardrail with a turndown end treatment (Figure IV-3), and the 60 mph short radius W-beam treatment (Figure III-1) were approximately 20 percent lower than those of the 45 mph short radius option for 2-lane and 4-lane rural collector roads, and all four types of urban roads.

(b) B/C ratios of the 62.5 ft length of straight guardrail with an ET-2000 end treatment option were only about 8 percent lower than the 45 mph short radius option for 2-lane rural arterial roads, and were either approximately equal to or greater than the 45 mph short radius treatment for 4-lane rural arterials.

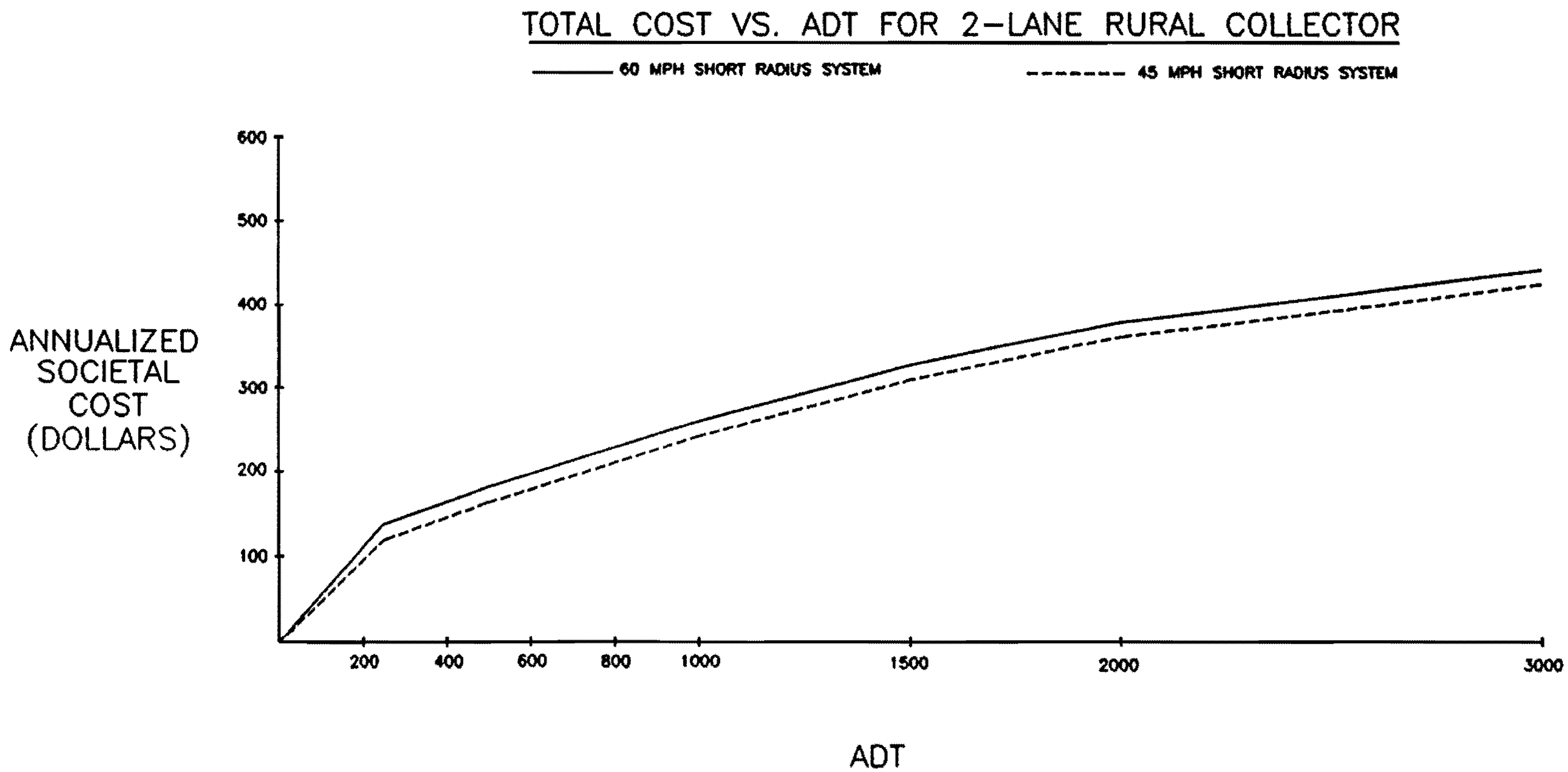


FIGURE IV-7. Annual Societal Cost vs. ADT for the 45 mph and 60 mph Short Radius W-Beam Systems

TABLE IV-2. Traffic Volume at Which Given Option Is Most Cost Beneficial - Category II Sites

Option	2-Lane Rural Collector	4-Lane Rural Collector	2-Lane Rural Arterial	4-Lane Rural Arterial	2-Lane Urban Collector	4-Lane Urban Collector	2-Lane Urban Arterial	4-Lane Urban Arterial
Do Nothing	<120	<150	<80	<100	<370	<480	<180	<220
45 mph Short Radius Nested W-Beam	≥120	≥150	≥80	100-17,000	≥370	≥480	≥180	≥820
W-Beam Rail with ET-2000	-	-	-	>17,000	-	-	-	-

4.4.3 Most Cost Beneficial Options - Category III Sites

This part of the analysis is applicable at sites, referred to as Category III sites, that have adequate space and longitudinal clearance between the bridge end and the intersecting road of 65 ft or more, such that options 4 through 8 can be used, but that have terrain conditions near the bridge end such that options 1, 2, and 3 cannot be used (see Section 4.1 for option descriptions). An example of a Category III site would be one where the intersecting road is approximately 65 ft from the bridge end and a side slope or ditch line runs parallel to the primary road near the bridge end. The side slope or ditch line would prohibit use of the short radius treatments near the bridge end. For such sites, the analysis identified the most cost beneficial options as a function of traffic volume for various roadway types.

Results are summarized in Table IV-3. Based on these results the following was concluded.

(a) Both the 62.5 ft length of straight guardrail with an ET-2000 end treatment option and the 62.5 ft length of straight guardrail with a turndown end treatment option had essentially the same B/C ratios and were the most cost beneficial options for 2-lane and 4-lane rural collector roads, and for all four types of urban roads.

(b) The 62.5 ft length of straight guardrail with an ET-2000 end treatment option was the most cost beneficial option for 2-lane and 4-lane rural arterial roads.

TABLE IV-3. Traffic Volume at Which Given Option Is Most Cost Beneficial - Category III Sites

Option	2-Lane Rural Collector	4-Lane Rural Collector	2-Lane Rural Arterial	4-Lane Rural Arterial	2-Lane Urban Collector	4-Lane Urban Collector	2-Lane Urban Arterial	4-Lane Urban Arterial
Do Nothing	<160	<200	<90	<120	<440	<580	<220	<290
W-Beam Rail with ET-2000	>150	>190	>40	>50	-	-	>220	>290
W-Beam Rail with Turndown	>150	>190	-	-	>440	>580	>220	>290

4.5 Summary of Results and Recommendations

Chapter V describes testing and further development of the 60 mph short radius W-beam system. The preliminary design used in the B/C analysis is shown in Figure III-1 and the as-modified version is shown in Figure V-15, and in Appendix E. Since the study terminated shortly after completion of the crash test program, a reevaluation of the B/C results using the modified design could not be made. However, as discussed in Section 5.7, it was estimated that the net effect of these changes on results of the B/C analysis would be relatively small.

As discussed in Section 5.5, although the 60 mph short radius system did not satisfy all design impact conditions, it is believed to have better impact performance characteristics than current designs and as such should be considered as an acceptable interim solution. Furthermore, test results indicate that it has impact performance capabilities equal to or greater than those estimated for the 45 mph short radius design examined in the B/C analysis. Until the 45 mph short radius design is verified through crash testing, the 60 mph short radius design is recommended in lieu thereof, where appropriate.

Results of the crash test program and the preceding B/C analysis were used as a basis for determining recommended use guidelines for safety alternatives at the subject sites. These recommendations are given in Table IV-4. Reference should be made to preceding sections for description of site categories. Note for Category II and III sites, more than one option is acceptable for certain roadway types.

The B/C analysis is based on the assumption that the intersecting roadway cannot be moved. However, if feasible, realigning or moving the intersecting roadway so that access to

TABLE IV-4. ADT Ranges for Recommended Treatment

Recommended Option	2-Lane Rural Collector	4-Lane Rural Collector	2-Lane Rural Arterial	4-Lane Rural Arterial	2-Lane Urban Collector	4-Lane Urban Collector	2-Lane Urban Arterial	4-Lane Urban Arterial
CATEGORY I SITES[a]								
Do Nothing	<120	<150	<80	<100	<370	<480	<180	<220
60 mph Short Radius Nested W-Beam (Figure V-15)	≥120	≥150	≥80	≥100	≥370	≥480	≥180	≥220
CATEGORY II SITES[b]								
Do Nothing	<120	<150	<80	<100	<370	<480	<180	<220
60 mph Short Radius Nested W-Beam (Figure V-15)	≥120	≥150	N/A	N/A	≥370	≥480	≥180	≥220
Straight W-Beam with ET-2000 (Figure IV-4)	≥120	≥150	≥80	≥100	≥370	≥480	≥180	≥220
Straight W-Beam with Turndown (Figure IV-3)	≥120	≥150	N/A	N/A	≥370	≥480	≥180	≥220
CATEGORY III SITES[c]								
Do Nothing	<150	<200	<90	<120	<440	<580	<220	<290
Straight W-Beam with ET-2000 (Figure IV-4)	≥150	≥200	≥90	≥120	N/A	N/A	≥220	≥290
Straight W-Beam with Turndown (Figure IV-3)	≥150	≥200	N/A	N/A	≥440	≥580	≥220	≥290

[a] See Section 4.5.1 for description.
[b] See Section 4.5.2 for description.
[c] See Section 4.5.3 for description.

the primary roadway is downstream from the standard length of guardrail is the preferred solution. An example of such a solution was found in the site survey conducted early in the project. Figure IV-8 shows a plan view of the site and photographs of the site are shown in Figure IV-9.

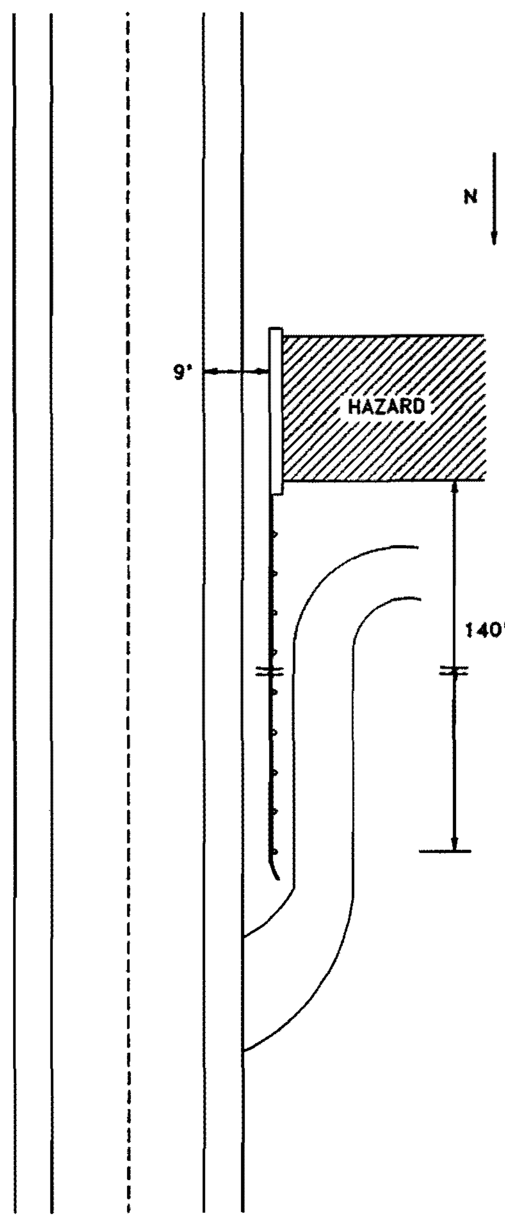


FIGURE IV-8. Diagram of Site with Realigned Secondary Roadway

Figure IV-9. Photographs of Site with Realigned Secondary Roadway

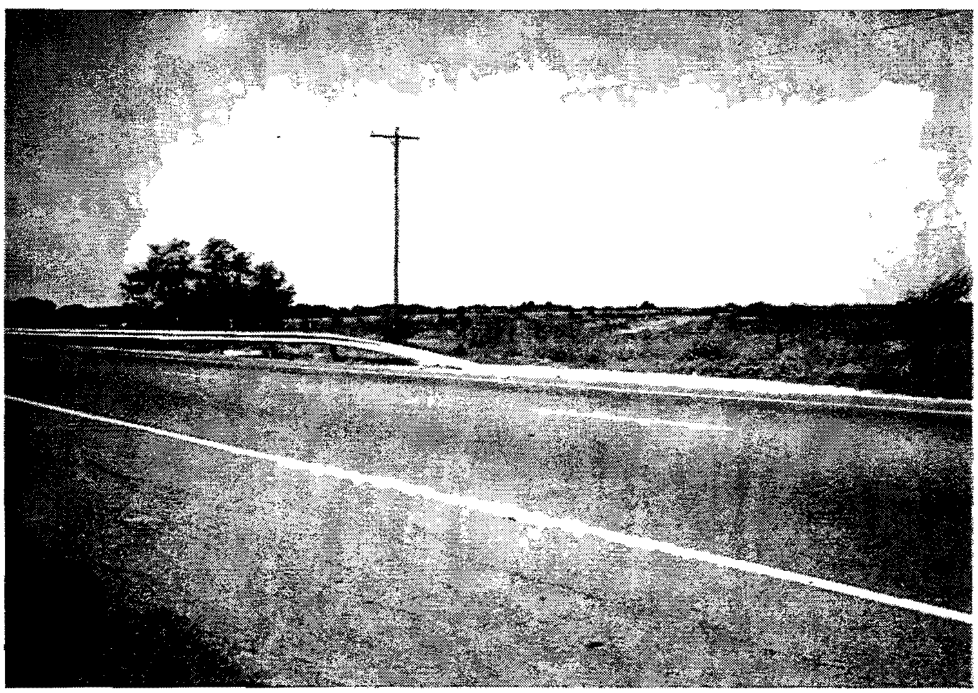


Figure IV-9. Photographs of Site with Realigned Secondary Roadway (continued)

V. FULL-SCALE CRASH TESTS

Results of the B/C analysis, described in previous chapter, indicated that both the 45 mph and the 60 mph short radius W-beam treatments, as shown in Figures III-1 and III-4, were cost beneficial for many site and traffic conditions. Of these two, the 45 mph treatment was indicated to have a wider range of application. However, since differences in the B/C ratio of the two were generally small, and since most sites had posted speed limits and operating speeds in excess of 45 mph, it was decided to construct and crash test a prototype of the 60 mph treatment.

As is commonly the case in the design of a roadside safety feature, it was necessary to modify the design as the test program progressed. Construction drawings of each as-tested installation are given in Appendix E. Complete details of the tests are given in Appendix F. Following is a summary of each test and modifications made to the design during the course of the test program.

5.1 Test 1263-1

In the initial crash test, the system shown in Figure V-1 was evaluated. With one small exception it is the same as the preliminary design described in Section 3.4.1 and shown in Figure III-1. Because the reinforcing steel in the existing safety shape bridge railing at the test site conflicted with the placement of the anchor bolts, the entire short radius system was shifted 1.5 in. upstream from the bridge end. This increased the distance from the bridge railing to the first post from 18.75 in. to 20.25 in. The overall effect of this change on system performance was believed to be negligible.

In this test a 1800 lb vehicle impacted the short radius system at 60 mph and 20 degrees, with the initial impact point near the center of the curved section. Photos of the installation are shown in Figure V-2. Photos of the vehicle and the installation after the test are shown in Figure V-3.

The system did not perform as designed for two reasons. First, upon impact, the weakened posts (referred to as CRT posts) in the curved portion began to rotate and were then pulled from the ground without fracturing as the vehicle continued to move forward. This had the effect of generating higher than expected impact forces on the vehicle. Secondly, the BCT

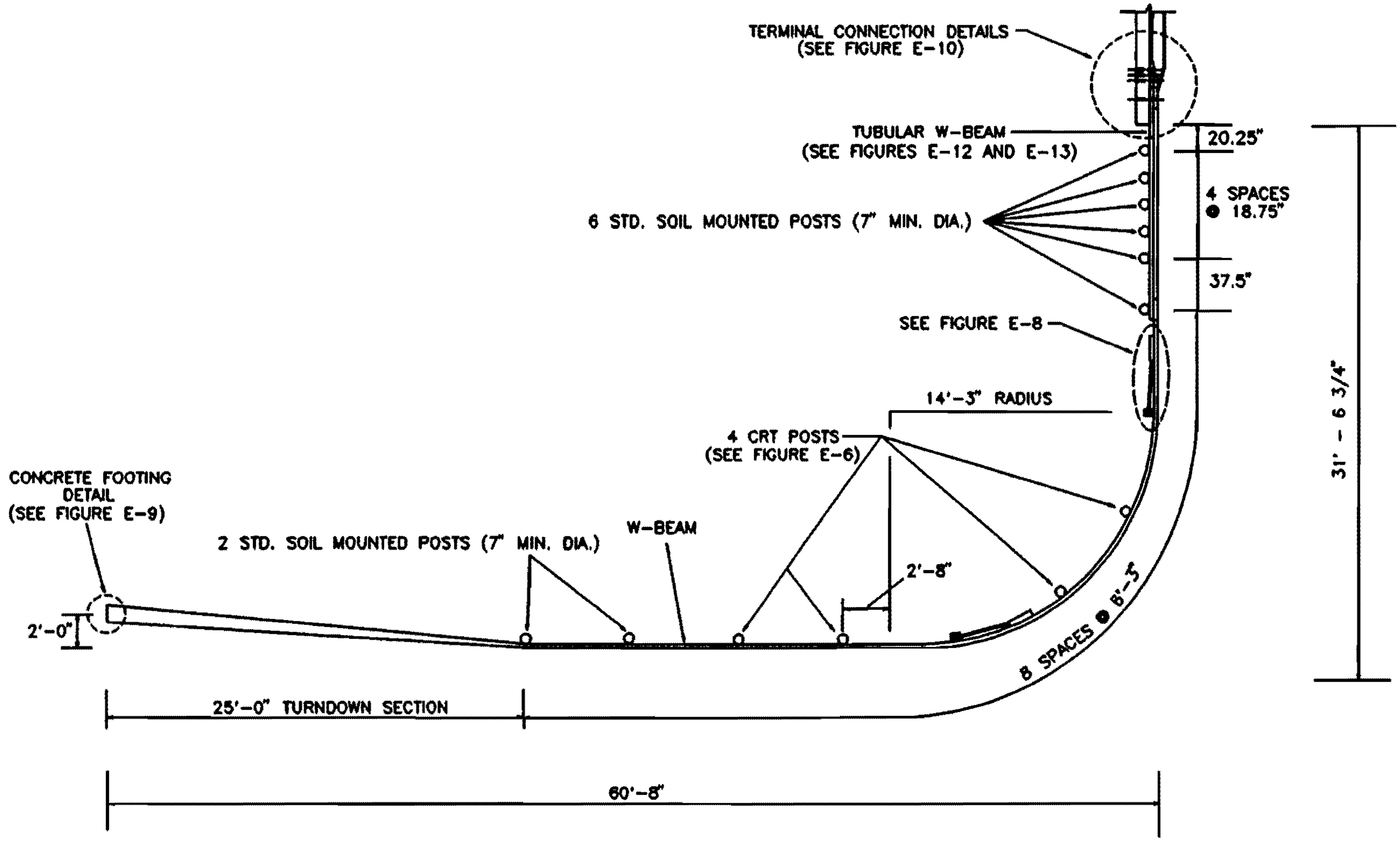


FIGURE V-1. 1263-1 Test Article

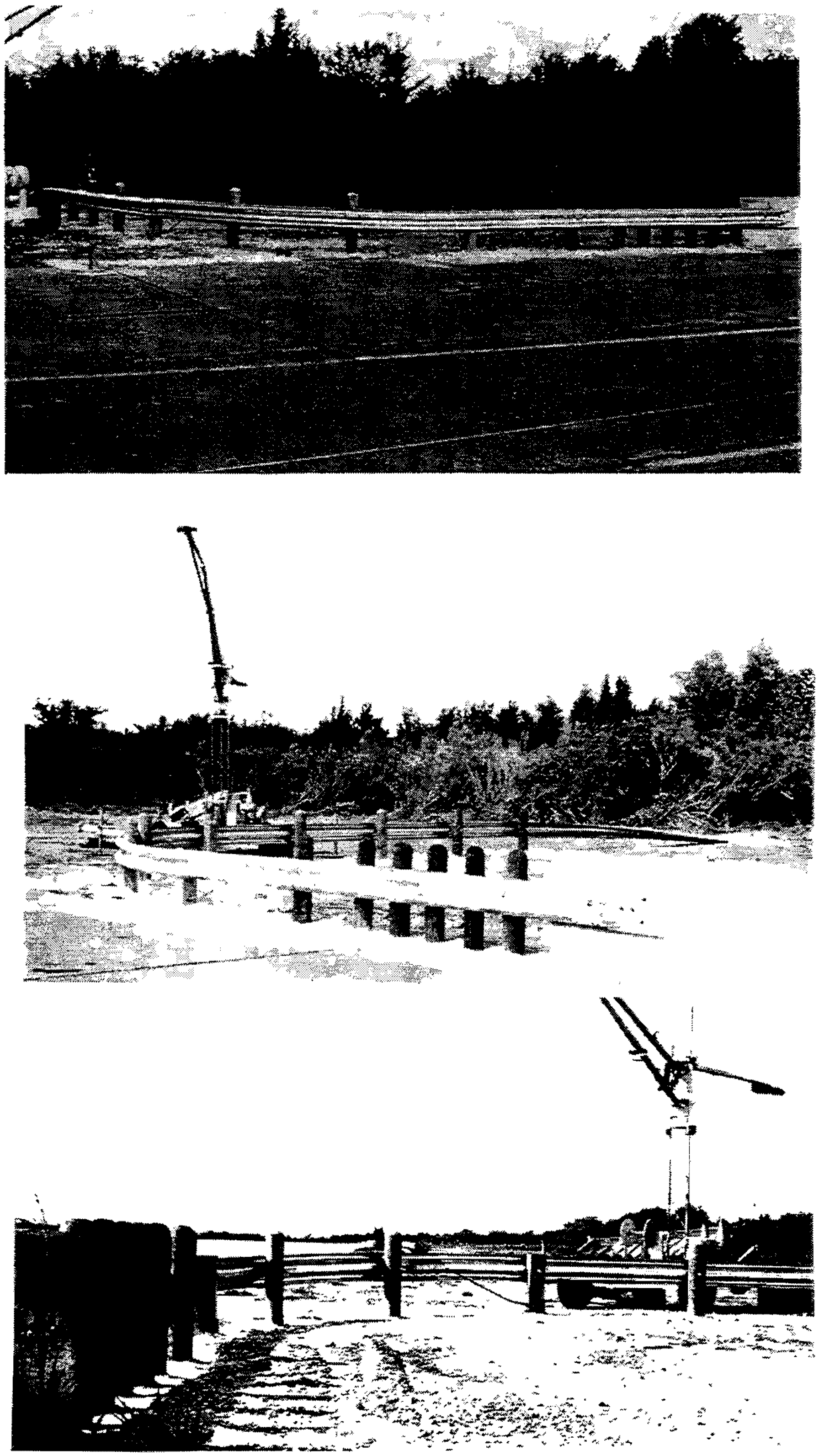


FIGURE V-2. Test Article Prior to Test 1263-1

FIGURE V-3. Test Vehicle and Test Article after Test 1263-1

post downstream from the impact point did not fracture as anticipated. This caused the rail to develop higher than expected tensile forces since the anchor cable could not release from the BCT post, which also contributed to higher than expected impact forces on the vehicle.

Longitudinal occupant impact velocity was 41.8 ft/s., which exceeded the limit of 40 ft/s recommended in NCHRP Report 230 (5). This was attributed to the unexpected system behavior previously described. Modifications made to improve performance are described in the next section.

5.2 Test 1263-2

Impact conditions for this test were the same as test 1263-1. However, two modifications were made to the installation of test 1263-1. First the most downstream BCT assembly was removed and the BCT post and sleeve was replaced by a weakened post. Secondly, the embedment depth of all weakened posts was increased from 38 in. to 44 in. to facilitate fracture of the posts during impact. The holes used to weaken the post were placed at the same location with respect to the ground line as in the previous test. These changes were used to reduce the stiffness of the system for impacts into the curved section. A plan view of the test installation is given in Figure V-4. Photos of the installation are given in Figure V-5.

The vehicle impacted the test article at approximately 60 mph and 20 degrees. Upon impact, the weakened posts in the curved portion of the system fractured as designed. However, as the vehicle continued to penetrate into the system the curved W-beam fractured at a splice, allowing the vehicle to travel well beyond the intended stopping distance. This was an unexpected and unacceptable failure. Photos of the installation after the test are given in Figure V-6.

Tensile tests were performed on a specimen from the torn w-beam by an independent test lab. Results (given in Appendix F, in section describing Test 1263-2) showed the material to be within specifications with regard to yield strength, ultimate strength, and ductility. It is noted that the material in a W-beam is subjected to stresses beyond the yield strength during the normal cold-forming process. The material is further yielded during the process of bending the rail into a curved section. This is believed to alter the ductility of the material, and to make the material more susceptible to a brittle-type failure, especially if a crack were present in high

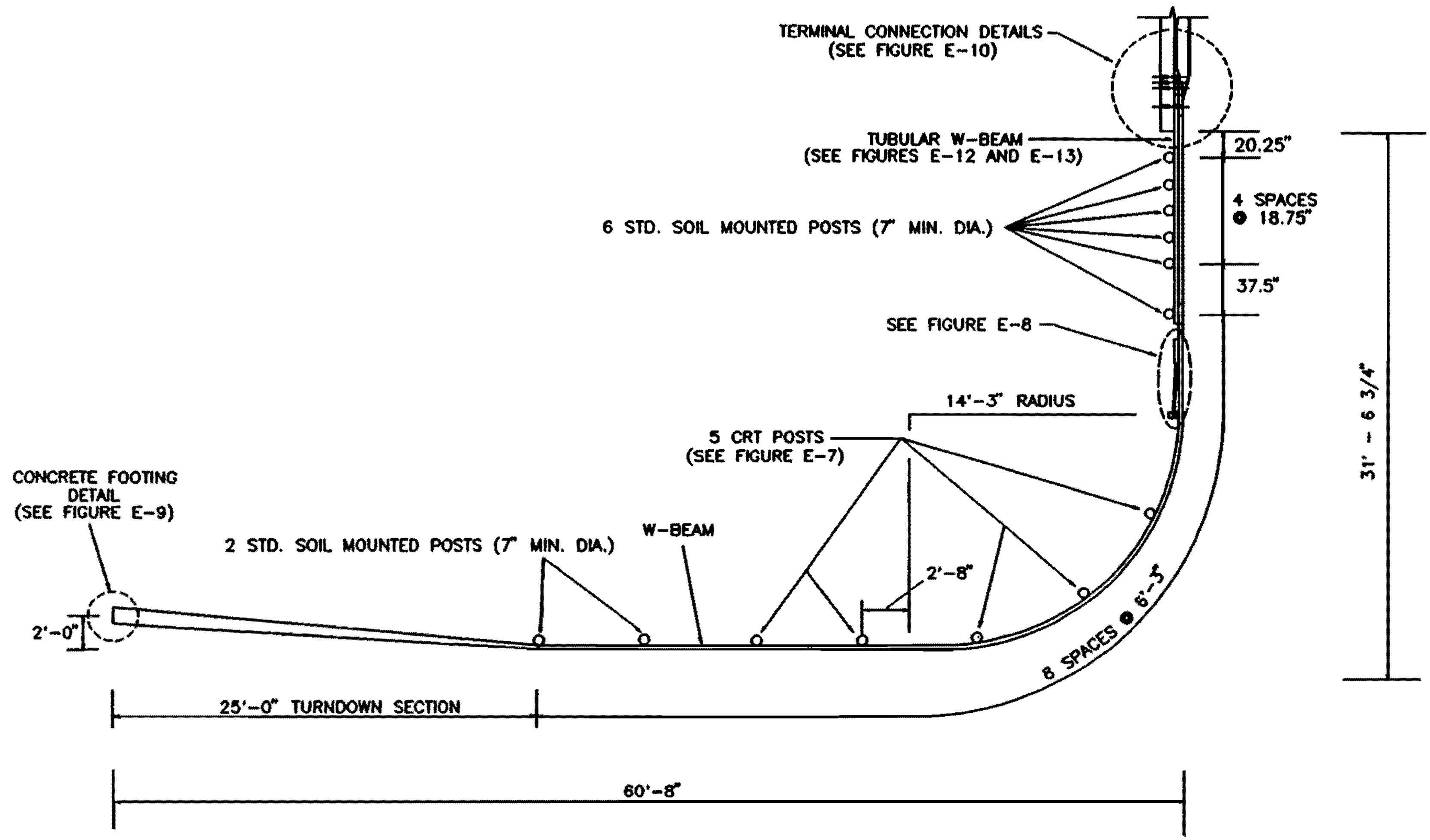
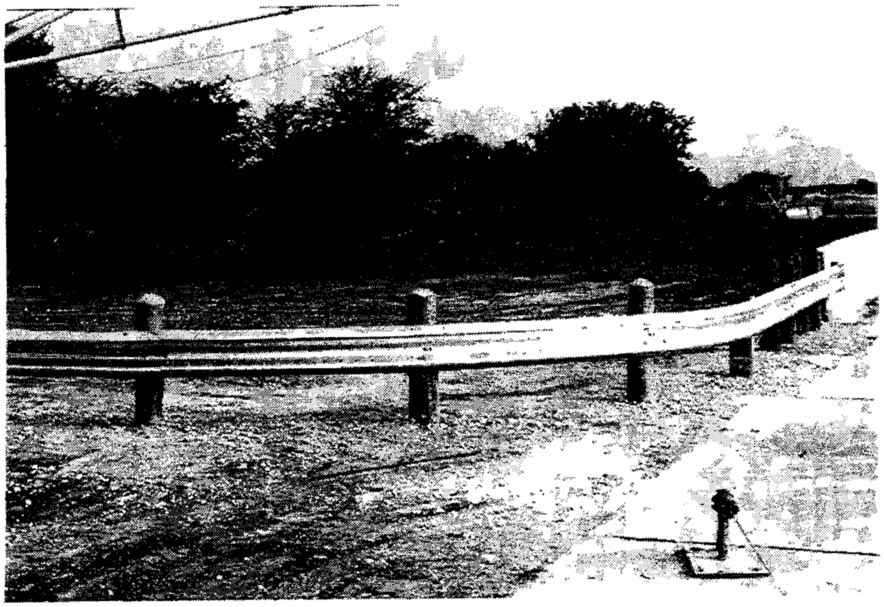


FIGURE V-4. 1263-2 Test Article



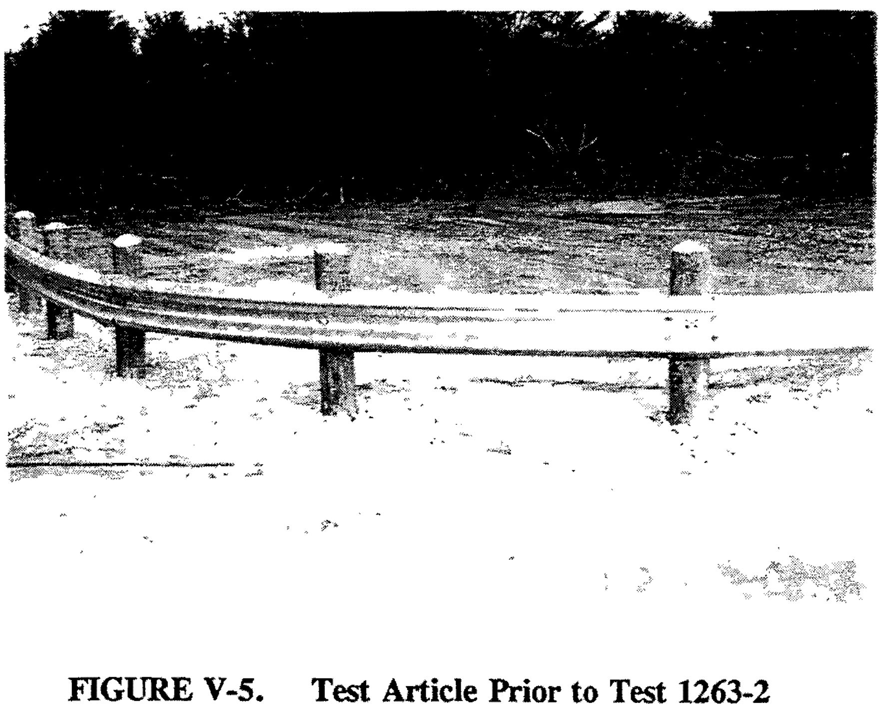


FIGURE V-5. Test Article Prior to Test 1263-2

FIGURE V-6. Test Article After Test 1263-2

stress areas of the beam. Further study of the effect these forming processes have on the impact strength of guardrail, and curved guardrail in particular, may be warranted.

5.3 Test 1263-3

Results of the first two tests were analyzed to determine how the installation could be further modified. It was concluded that the W-beam rail could be strengthen without adversely effecting the impact performance of the small car. To do this, two W-beams were nested, one behind the other, throughout the length of the installation, with the exception of the turndown section and the tubular W-beam section in the transition area. This in effect doubled the bending and axial load capacity of the system. A plan view of the installation for this test is given in Figure V-7. Photos of the installation are given in Figure V-8.

Impact conditions were the same as the previous two tests. The vehicle impacted the system at approximately 60 mph and 20 degrees, was brought to a stop in approximately 14 ft. Measured occupant risk values were below recommended limits of NCHRP Report 230 (5), and the test was considered successful. Photos of the installation and the vehicle after the test are given in Figure V-9.

5.4 Test 1263-4

A plan view of the installation for this test is shown in Figure V-10. The only modification made in this installation compared to the previous installation was an increase in the radius of the curved portion from 14 ft-3 in. to 16 ft. This change was made to simplify installation since posts now fell at both the beginning and end of the curved portion. It also allowed for interchangeability of the 12.5 ft straight-curved section of rail at the beginning and end of the curved portion of the installation. Photos of the installation are given in Figure V-11.

This test was conducted to ascertain the redirective capability of the system's transition region. Test conditions followed the recommendations of NCHRP Report 230 (5) for transitions. This consisted of a 4500 lb vehicle impacting at 60 mph and 25 degrees at the critical impact along the transition. In this case, the critical impact point was determined to be approximately 75 in. from the end of the concrete safety shape. The vehicle was safely redirected with minimal wheel snagging. The test successfully met all recommended evaluation

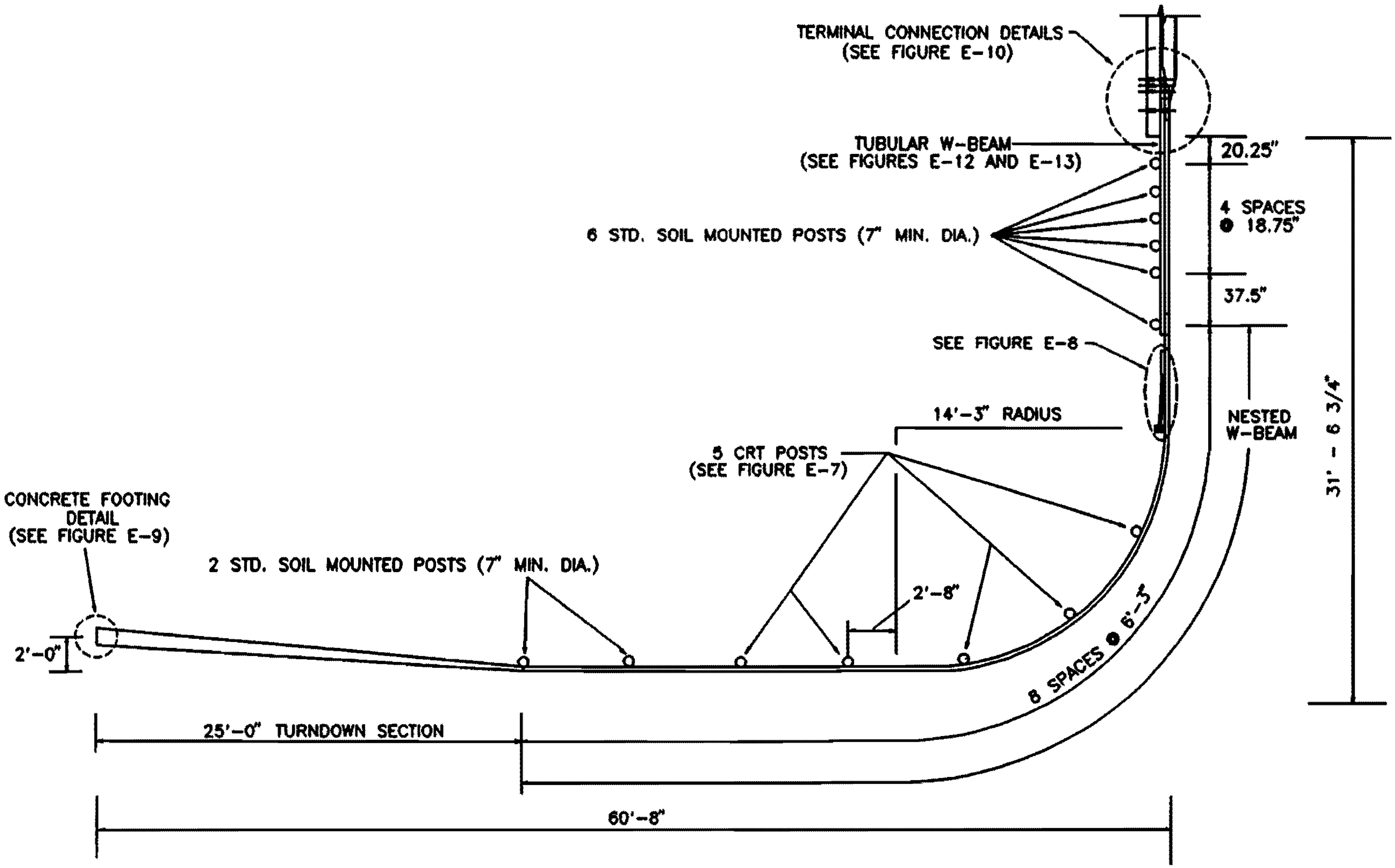
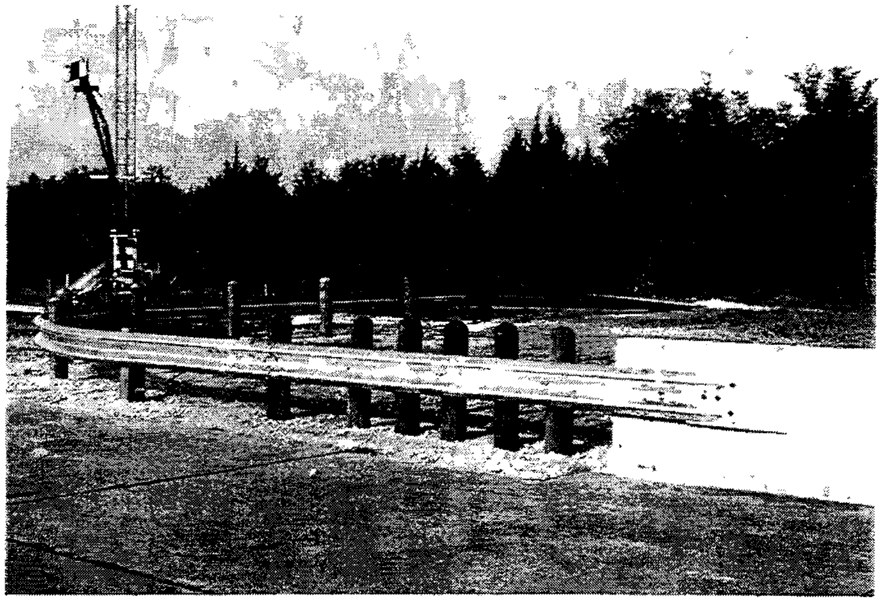


FIGURE V-7. 1263-3 Test Article



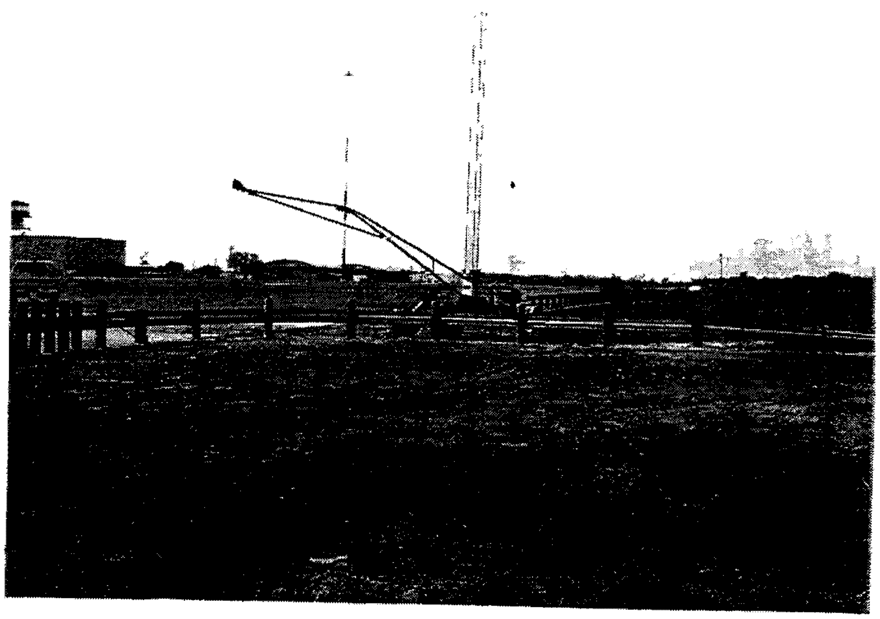


FIGURE V-8. Test Article Prior to Test 1263-3

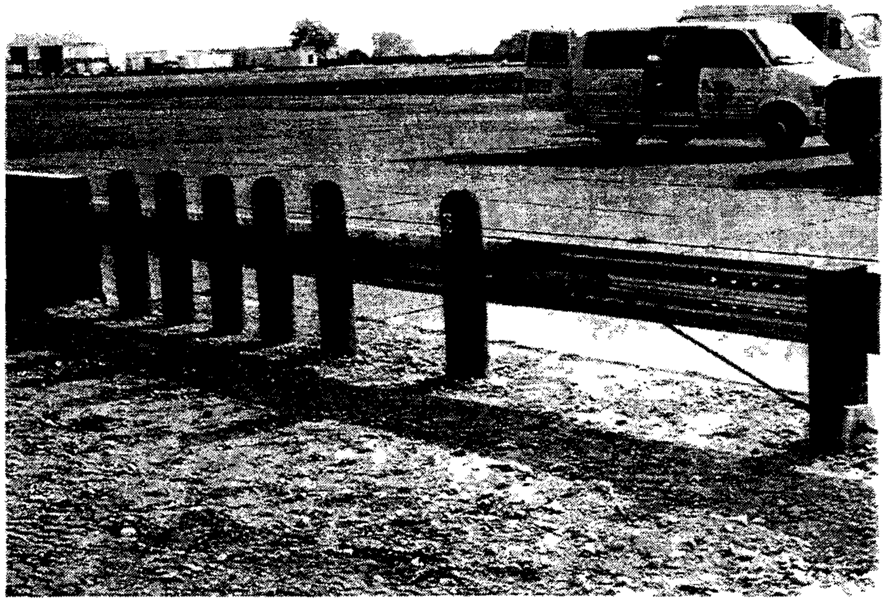


FIGURE V-11. Test Article Prior to Test 1263-4 criteria of NCHRP Report 230. Photos of the installation and the vehicle after the test are given in Figures V-12 and V-13.

It can be seen that the door panel on the driver's side was separated during impact. This occurred at the juncture of the tubular W-beam with the "end shoe." It was necessary to lap the end shoe on the outside of the tubular W-beam section, which created a minor snag point. Although it is not believed necessary, it may be desirable to develop a splice that would preclude this occurrence.

5.5 Test 1263-5

The installation for this test was identical in design to the one of test 1263-4. The test consisted of a 4500 lb vehicle impacting at the midpoint of the curved portion at approximately 60 mph and 25 degrees. The purpose of this test was to determine if the short radius system could safely contain a large vehicle without allowing excessive deflections or vehicular penetration.

Upon impact the posts in the impact area fractured as intended as the rail was deflected. However, after deflecting the system approximately 16 ft the nested w-beam guardrail began to ride up over the bumper of the vehicle. At this point the vehicle had been decelerated from its initial impact speed of 58.5 mph to approximately 36 mph, a loss of approximately 62 percent of its initial kinetic energy. As the vehicle continued to deform the system, the rail began to knife into and ride up over the grill, engine and front wheels of the vehicle. Just prior to the time the rail went over the roof of the vehicle, the system had been deflected about 28 ft and the speed of the vehicle had been slowed to less than 20 mph, a loss of over 88 percent of its initial kinetic energy.

Photos of the installation and the vehicle after the test are given in Figures V-14 and V-15. Damage to the vehicle was extensive, and the W-beam rail caused significant deformations of the occupant compartment as the vehicle went under the barrier.

The test was a failure since the vehicle penetrated beyond the barrier, and since damage to the occupant compartment was unacceptable. These results notwithstanding, there were positive aspects of the test. First, prior to the vehicle underriding the rail, the system had dissipated almost 90 percent of the vehicle's initial kinetic energy, and occupant risk parameters during this phase were well below recommended limits. It can therefore be inferred that the

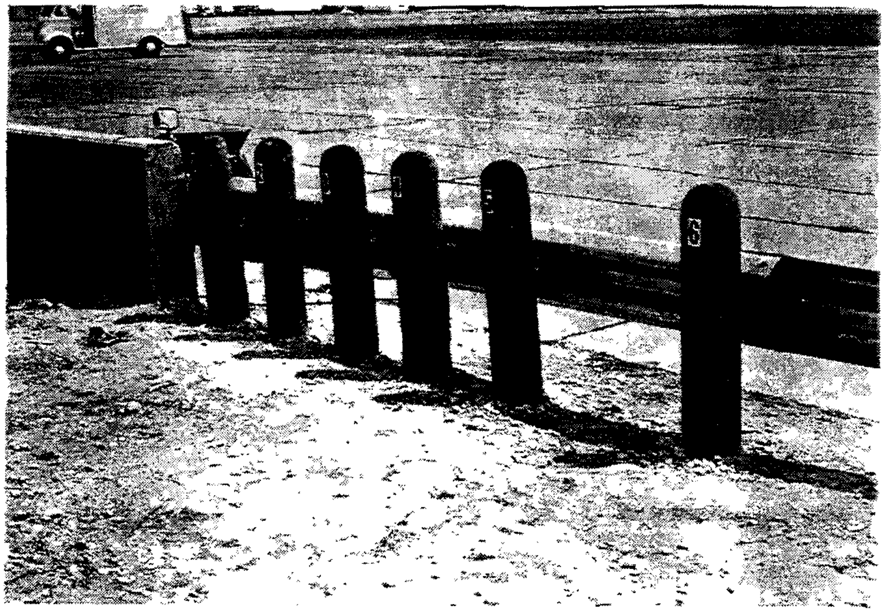


FIGURE V-12. Test Article After Test 1263-4

FIGURE V-13. Test Vehicle After Test 1263-4

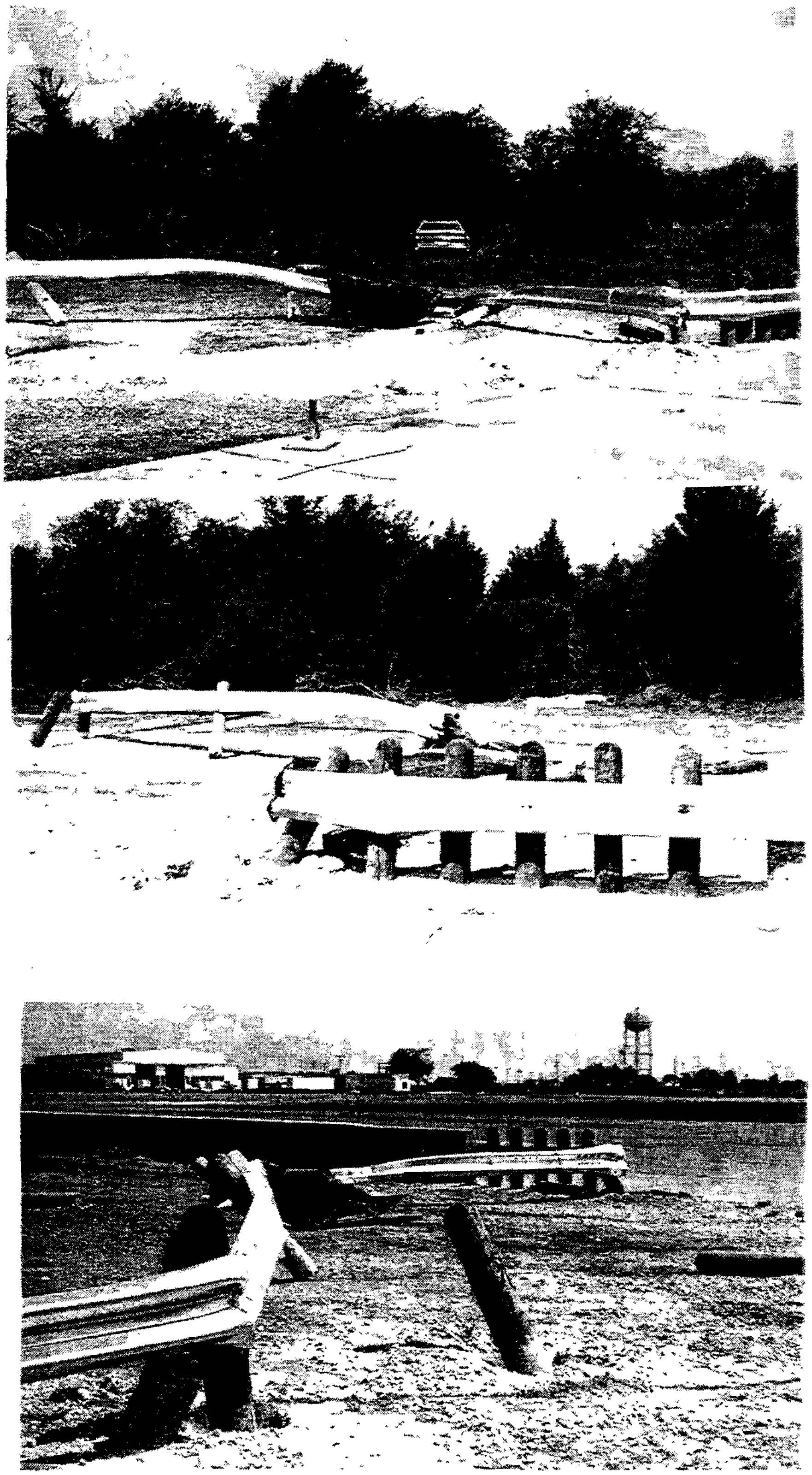


FIGURE V-14. Test Article After Test 1263-5

FIGURE V-15. Test Vehicle After Test 1263-5

system would have safely contained the vehicle had the impact speed been approximately 55 mph or less. This means that the system has the capacity to contain the vast majority of expected impacts. Secondly, based on results of tests 1263-3 and 1263-5, it was concluded that the system's performance could be improved to the point of meeting NCHRP Report 230 (5) evaluation criteria by replacing the nested W-beam rails with a single 10 gauge thrie beam rail. A 10 gauge thrie beam has approximately the same section properties (area, section modulus, and second moment of area) as do two nested 12 gauge W-beam rails, and it has a width (vertical dimension) of 20 in., compared to 12.25 in. for the W-beam. The thrie beam is typically installed with a ground clearance of 12 in., whereas the W-beam typically has a ground clearance of 14.75 in. If necessary, the thrie beam could be lowered to provide a ground clearance less than 12 in. The combined effect of increased height and lower ground clearance of the thrie beam should prevent the underriding observed with the W-beam. Installation of the curved, nested W-beam rail proved to be very difficult since the splice holes did not readily align. Forced alignment (by use of driven alignment pins) was required to install the splice bolts, and this almost certainly induced high localized and residual stresses that could cause cracks, and ultimately failure of the beam. Splicing a single curved thrie beam would be considerably less difficult.

An additional minor modification to the installation seemed warranted as a result of test 1263-5, regardless of whether the nested W-beam is replaced with the thrie beam or not. It was concluded that the post adjacent to the one at the beginning of the turndown rail should be weakened. The rail was seen to ride up and over this post in test 1263-5, which may have contributed to the underriding problem. When weakened, the post should fracture as the load in the rail increases, reducing the tendency for the rail to ride up on the post. Figure V-16 shows the installation incorporating this change.

5.6 Test 1263-6

This test, the last of the series, was selected to evaluate the system's redirective capability for an impact in the curved portion at a shallow impact angle to insure that the vehicle did not penetrate into the more rigid transition region. The fore-aft centerline of the vehicle was aligned with the centerline of that portion of the guardrail parallel to the primary road. When aligned in this manner, initial vehicular contact was in the curved section of the treatment.

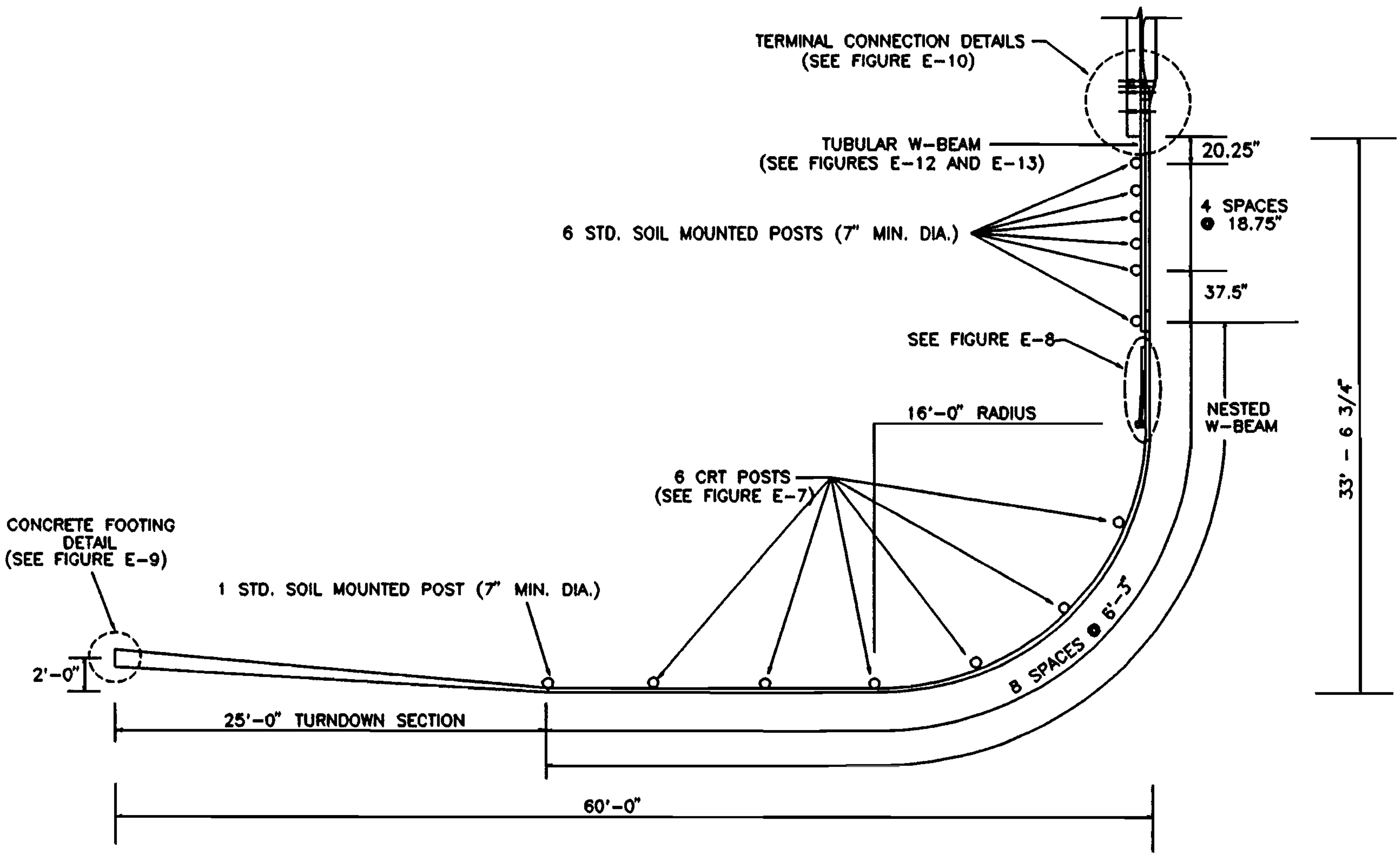


FIGURE V-16. 1263-6 Test Article

A plan view of the test installation is shown in Figure V-16. It was identical to the one of test 1263-5 with the exception that the post adjacent to the one at the beginning of the turndown rail was weakened. The reason for this modification was given in Section 5.5.

The vehicle impacted the curved portion of the system at 58.3 mph at an angle of 2.0 degrees. The vehicle was smoothly redirected, and the test met recommended evaluation criteria of NCHRP Report 230 (5). Damage to the barrier and to the vehicle was relatively small. Photos of the installation and the vehicle after the test are given in Figures V-17 and V-18.

5.7 Summary

A summary of crash test results is given in Table V-1. As previously discussed, the short radius system underwent several design changes during the course of the crash test program. The radius was increased slightly, one of the BCT assemblies was removed, the weakened CRT posts were embedded an extra 6 in., and a 50 ft section of the W-beam rail was nested. While these changes may increase the cost of the system, the installed cost should not increase significantly above that assumed for the original design evaluated in the benefit-cost analysis of Chapter IV. Thus, results obtained in the benefit-cost analysis should not change appreciably. Time limitations of the study precluded a reevaluation of the modified 60 mph short radius system in the benefit-cost analysis following the crash test program.

It is noted that the length of the system along the intersecting roadway could possibly be shortened by 25 ft by eliminating the turndown rail and by substituting a "dead man" cable anchor with no breakaway feature at the last post. This alternative may be applicable where right-of-way is limited and risks of serious impact with the untreated guardrail end are minimal. For example, if the intersecting roadway is used only for access to farm land, approach speeds of vehicles from the intersecting road to the primary road would likely be very low.

With one exception, the 60 mph short radius system passed each of the four crash tests selected as design impact conditions. The one failure involved a 4,500 lb vehicle impacting at the center of the curved portion at approximately 60 mph and an impact angle of 25 deg. In that test the vehicle went under the guardrail. Analysis of the test results indicated that the system dissipated approximately 90 percent of the vehicle's initial kinetic energy prior to allowing it to underride the guardrail (see discussion in Section 5.5). Therefore, since the 4,500 lb/60 mph/25

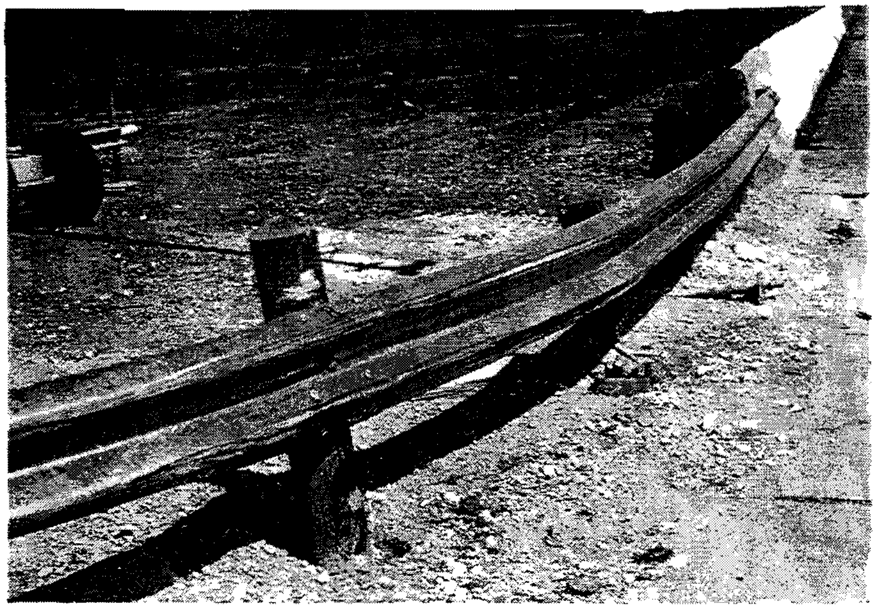
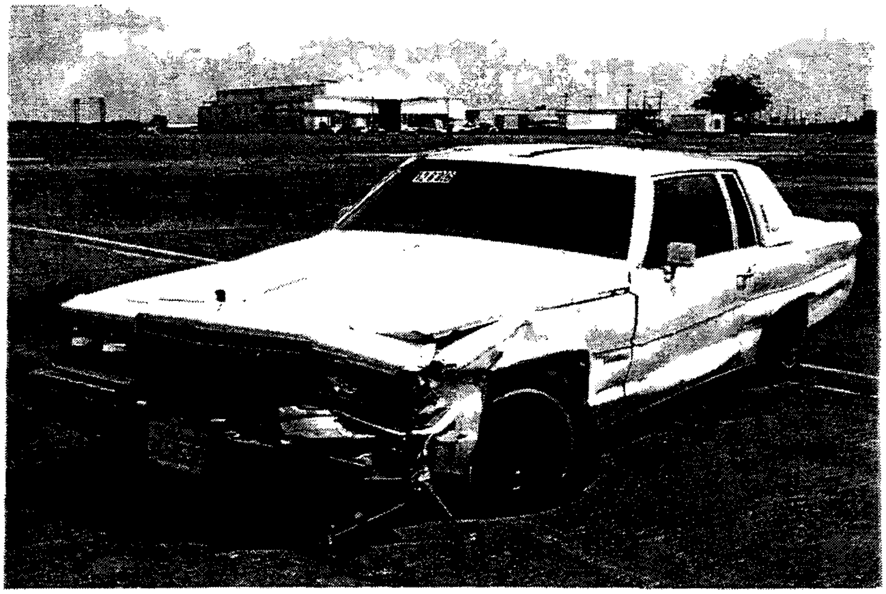


FIGURE V-17. Test Article After Test 1263-6



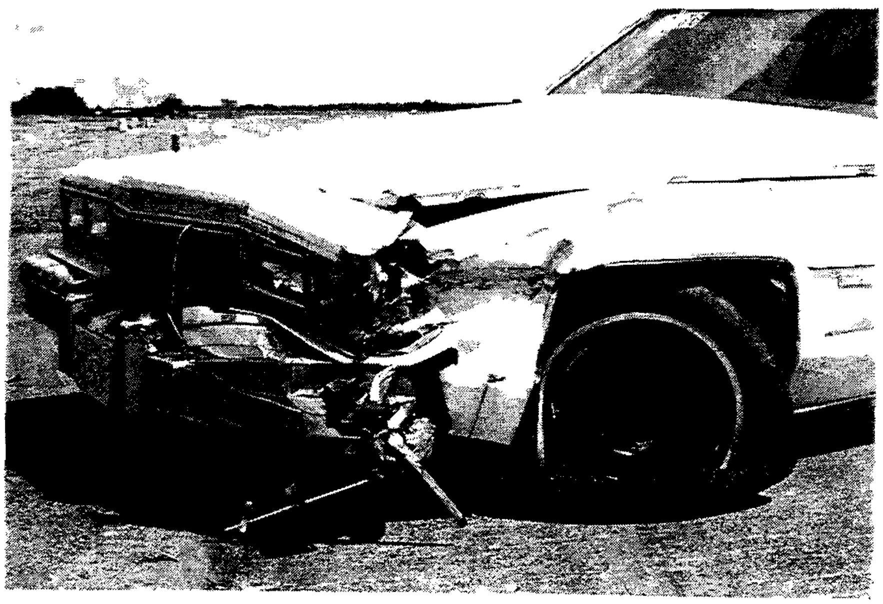


FIGURE V-18. Test Vehicle After Test 1263-6

TABLE V-1. Summary of Crash Test Results for 60 mph Short Radius End Treatment

Test No.	1263-1	1263-2	1263-3	1263-4	1263-5	1263-6
Test Vehicle	1987 Yugo	1987 Yugo	1987 Yugo	1982 Cadillac	1982 Cadillac	1982 Cadillac
Gross Vehicle Weight, lb.	1970	1970	1968	4500	4500	4500
Impact Speed, mph	58.4	59.0	60.2	57.1	58.5	58.3
Impact Angle, deg	20.5	20.4	20.0	24.7	26.8	2.0
Exit Angle, deg	Did Not Exit	Did Not Exit	Did Not exit	9	Did Not Exit	16.6
Exit Speed, mph	Did Not Exit	Did Not Exit	Did Not Exit	42.2	Did Not Exit	52.8
Max. 50 msec Avg Accel Longitudinal - g's Lateral - g's	 -16.3 5.0	 -9.9 2.2	 -13.2 3.4	 -9.1 10.5	 -5.6 2.1	 -2.4 -4.8
Occupant Impact Velocity Longitudinal - fps Lateral - fps	 41.7 10.7	 27.4 4.2	 34.3 7.9	 27.6 25.4	 20.3 -6.2	 10.7 15.4
Ridedown Acceleration Longitudinal - g's Lateral - g's	 -12.8 2.5	 -10.5 0.8	 -8.9 -3.5	 -4.8 -7.7	 -7.5 2.3	 -1.6 -5.6
NCHRP Report 230 Evaluation Structural Adequacy (A,D) Occupant Risk (E) Vehicle Trajectory (H,I)	 Passed Failed Passed	 Failed Passed Failed	 Passed 40>Long. ΔV>30 Passed	 Passed 30>Lat. ΔV>20 Passed	 Failed Passed Failed	 Passed Passed Passed

deg test conditions represent the extreme of real world impact conditions, the system can be expected to perform as intended for most impact conditions.

In the absence of a more cost beneficial system that meets all impact performance requirements, consideration should be given to implementation of the 60 mph short radius, nested W-beam treatment, at least as an interim solution. With one exception, details of the recommended design are given in Figure V-16 and in Figures E-7 through E-15 in Appendix E. The one exception is that the 20.25 in. distance between the bridge end and the first post in the transition region should be changed to 18.75 in. for consistency in post spacing in the transition region (see discussion in Section 5.1). As discussed in Section 5.5, consideration should also be given to the development and use of system similar to the as-tested system, with a single 10 gauge thrie beam in lieu of the nested W-beam. It is believed that such a system would satisfy all design impact conditions, would be easier to install, and the cost of such a system would not be appreciably different from the nested W-beam system. It would be necessary to design a new transition section for the thrie beam system; however, it is believed that a nested thrie beam transition section would prove to be satisfactory.

Finally, based on results of the B/C analysis, consideration should also be given to the development and testing of a 45 mph short radius design. Indications are that such a design would have application at a number of sites, especially those with reduced speeds and/or lower volume roads.

Construction drawings of each as-tested installation are given in Appendix E. Complete details of the tests are given in Appendix F.

VI. CONCLUSIONS AND RECOMMENDATIONS

This study was undertaken to address the problem of bridge ends on primary roads that are near intersecting roads. At these sites, the standard guardrail treatment for the bridge end cannot be used because of insufficient run-out length, and alternate treatments are needed. The study approach consisted of (a) a survey of typical sites to identify the nature of the problem, (b) design of preliminary short radius guardrail treatments (c) a benefit/cost analysis of available systems, plus proposed new short radius guardrail treatments, that could potentially be used at these sites, (d) development and crash testing of a short radius guardrail treatment, and (e) identification of recommended solutions to the problem for various types of roadways. As a result of this research, the following conclusions were made.

(1) Surveys of problem sites indicated that conditions such as roadway type, traffic volume, and the lateral offset of the bridge end from the travelway vary from site to site. The variable of primary concern was the longitudinal clearance from the bridge end to the intersecting roadway. This dimension was found to vary from only a few feet to over 65 ft. For purposes of this study, the sites were divided into one of three categories: (I) those with a longitudinal clearance of approximately 35 ft and no restrictions in the lateral direction, (II) those with a longitudinal clearance of 65 ft or more and no restrictions in the lateral direction, and (III) those with a longitudinal clearance of 65 ft or more but with restrictions in the lateral direction such that a curved guardrail treatment could not be used.

(2) Three short radius guardrail treatments were designed, consisting of two 60 mph designs and a 45 mph design. One of the 60 mph designs used the standard W-beam and the other used the thrie beam. The 45 mph design used nested W-beam rails.

(3) Benefit/cost analysis was used to evaluate various safety treatments. Treatments included (a) three short radius guardrail designs, (b) the TREND system, (c) an inertial crash cushion (sand tubs), (d) a straight W-beam barrier system, 65 ft in length, consisting of a transition (from W-beam to bridge abutment) section, a standard section, and a turndown end treatment, (e) a straight W-beam barrier system, 65 ft in length, consisting of a transition section, a standard section, and an ET-2000 end treatment, and (f) a straight/curved W-beam barrier system, consisting of a transition section, a straight

standard W-beam section, and a curved W-beam end treatment, with a net longitudinal clearance of 65 ft. The benefit/cost analysis was used to identify the most cost beneficial alternative as a function of site category (as defined in item 1 above), roadway type, and traffic volume. Specific findings and recommended use guidelines are given in Chapter IV. As a general rule, the results indicate that some type of safety treatment is desirable on rural collector and arterial roads with ADT's in excess of about 100, and on urban collector and arterial roads with ADT's in excess of about 200.

(4) A short radius, curved W-beam treatment, designed for impacts up to 60 mph, was subjected to a full-scale crash test program. Modifications were made to the design as the test program progressed. With one exception, the 60 mph short radius system passed each of the four crash tests selected as design impact conditions. The one failure involved a 4,500 lb vehicle impacting at the center of the curved portion at approximately 60 mph and an impact angle of 25 deg. In that test the vehicle went under the guardrail. Analysis of the test results indicated that the system dissipated approximately 90 percent of the vehicle's initial kinetic energy prior to allowing it to underride the guardrail (see discussion in Section 5.5). Therefore, since the 4,500 lb/60 mph/25 deg test conditions represent the extreme of real world impact conditions, the system can be expected to perform as intended for most real-world impact conditions.

Recommendations

(1) When feasible, the intersecting roadway should be realigned or moved so that access to the primary roadway is downstream from the standard length of guardrail. An example of this solution is shown in Figures IV-8 and IV-9 (see discussion in Section 5.7 concerning recommended design details of treatment).

(2) As discussed in Section 5.5, consideration should be given to the development and use of a system similar to the as-tested system, with a single 10 gauge thrie beam in lieu of the nested W-beam. It is believed that such a system would satisfy all design impact conditions, would be easier to install, and the cost of such a system would not be appreciably different from the nested W-beam system. It would be necessary to design a new transition section for the thrie beam system; it is believed that a nested thrie beam transition section would prove to be satisfactory.

(3) Based on results of the B/C analysis, consideration should be given to the development and testing of a 45 mph short radius design. Indications are that such a design would have application at a number of sites, especially those with reduced speeds and/or lower volume roads.

(4) Consideration should be given to implementation of the use guidelines in Section 4.5 for safety treatments at problem sites.

(5) An evaluation of the effect forming and/or rolling processes have on the impact strength of guardrail, and curved guardrail in particular, should be considered (see discussion in Section 5.2).

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APPENDIX A

BARRIER VII COMPUTER SIMULATION

BARRIER VII COMPUTER SIMULATION

When a secondary road or driveway intersects a primary roadway in close proximity to a bridge end, standard lengths of approach guardrail cannot be installed. Under these circumstances, other safety treatments such as a short radius guardrail system must be implemented. The purpose of a short radius guardrail treatment is not only to shield vehicles from the bridge rail end, but also to prevent errant vehicles from penetrating behind the bridge rail where they may encounter severe hazards.

The typical short radius guardrail treatment consists of a transition from the bridge rail to the more flexible approach guardrail and a curved portion of guardrail which turns the barrier down the secondary roadway where it is anchored. When designing such a system, the impact performance of both of these regions must be considered. The transition must have sufficient strength to redirect impacting vehicles and prevent them from snagging on the end of the bridge rail, and the curved portion of rail must be able to safely contain and decelerate both a 4500 lb and 1800 lb vehicle.

However, analysis of vehicular impacts with roadside barriers is a very complex task. In fact, in view of the complexity of these dynamic interactions, the only practical and reliable approaches for evaluating the impact performance of protective barriers are full-scale crash testing and computer simulation. Although full-scale crash testing is the most accurate method for evaluating barrier impact behavior, such tests are extremely expensive and, therefore, cannot be used as a routine design tool to investigate the performance of numerous design concepts. Computer simulation programs, on the other hand, provide a relatively inexpensive alternative for evaluating the impact performance of various design alternatives.

The Barrier VII computer simulation program (3) was chosen as the most appropriate program for this study. Barrier VII is a two-dimensional finite-element program that models vehicular impacts with deformable barriers. The program employs a sophisticated barrier model that is idealized as an assemblage of discrete structural members possessing geometric and material nonlinearities. The available structural members include beams, cables, posts, columns, springs, links, and damping devices. Simulated guardrail beam elements are assumed to be of uniform cross section and to have bilinear elastic/perfectly plastic properties both flexurally and extensionally. The strength, stiffness, and material properties are assigned by the user for each barrier element. Relevant material specifications for W-beam guardrail can be found in AASHTO specification M-180-74 (11).

Post members are used to represent all attachments of a barrier to the ground or to a rigid object. Stiffness for elastic horizontal displacements and base yield moments are assigned to the post for both longitudinal and lateral directions. Failure of a post may occur in one of two ways. A deflection failure can be used to represent separation of the rail from the post as the post rotates in the soil, or withdrawal of the post from the ground. A shear failure can be specified to represent fracture of a weakened post. Several types of posts were present in the short radius design. These included 7 in. diameter standard timber posts, and two types of timber breakaway posts. Details of how these posts were modeled are discussed in the following sections.

The planar vehicle model incorporated into Barrier VII is described by a number of discrete omnidirectional inelastic springs. These springs define the shape of the vehicle and the possible contact points at which the vehicle may interact with the barrier. The spring stiffnesses, as well as the initial impact speed, angle, and position of the vehicle, are specified by the user.

Barrier VII Validation

Before any simulation program can be useful as a reliable design tool, it must first be validated against the results of full-scale crash tests for the particular application of interest. Although Barrier VII has been well validated for use in the development of a variety of flexible barriers, its use in simulating headon impacts into a curved section of guardrail has been limited. Therefore, one of the first steps accomplished in the design of the short radius guardrail was to conduct a limited validation of Barrier VII for impacts in this region.

One problem encountered in this effort was the lack of acceptable short radius designs available to validate against. The only treatment which has been tested at speeds of 60 mph is a system that was developed under a recent FHWA study (2). The system, shown in Figure I-1, consists of a W-beam rail curved in a 8 ft-6 in. radius and terminated with a modified break-away cable terminal (BCT) 25 ft down the secondary roadway. Weakened posts spaced at 6 ft-3 in. were used along the curved portion of the rail. At the time this simulation study was performed, only two tests had been conducted that could be used for this validation effort.

Test WA-1M involved a 1900 lb vehicle impacting the midpoint of the curved section of rail at a speed of 60 mph and at an angle of 23.7 degrees. The second test, test WA-4M, involved a 4640 lb vehicle impacting the midpoint of the curved portion of the system at 58.8 mph and 14.6 degrees. Table A-1 shows a comparison of the crash test results with those estimated from the Barrier VII simulations. Barrier deflection and occupant impact velocity were selected as the primary measures of correlation between the simulations and crash tests.

Table A-1. Barrier VII Validation Results

Test No.	Full-Scale Crash Test			Barrier VII Simulation		
	Deflection (ft)	Occ. Impact Velocity (ft/sec)		Deflection (ft)	Occ. Impact Velocity (ft/sec)	
		Long.	Lateral		Long.	Lateral
WA-1M	12.8	37.9	16.6	11.3	40.6	2.6
WA-4M	N.A.	16.6	6.3	30.0	26.9	11.0

It should be noted that in test WA-4M the BCT end anchorage failed and the test vehicle was not contained by the barrier. In the Barrier VII simulation runs, the anchorage did not fail and the vehicle was contained. However, occupant risk values were measured before the failure of the anchorage and thus provided some means of comparison for the large car impact.

As shown in Table A-1, the simulations tended to overpredict the severity of impact into the curved segment of the short radius system. Generally speaking, Barrier VII predicted smaller dynamic deflections and greater occupant impact velocities. Although the data was very limited, these conservative results fostered some confidence in the use of the Barrier VII program for modeling impacts into the curved section of rail.

Short Radius Guardrail Design

Having completed the limited validation effort described above, the Barrier VII computer program was used to analyze the short radius guardrail problem. Four different impact cases were simulated to help identify deficiencies in the system and to assure that the system was analyzed under its most critical condition.

The first of these impact conditions was an occupant severity test which involved an 1800 lb vehicle impacting the midpoint of the curved section of guardrail at 60 mph and at an angle of 20 degrees. This test was intended to evaluate the potential risk of an occupant during the impact event. The occupant risk criteria outlined in NCHRP Report 230 require that the vehicle be decelerated at a rate such that the longitudinal ridedown acceleration and occupant impact velocity are less than 20 g and 40 ft/sec, respectively. The second simulated impact condition was primarily a strength test which involved a 4500 lb vehicle impacting the midpoint of the curved segment of rail at a speed of 60 mph and an angle of 25 degrees. The intent of this test was to examine the structural adequacy of the guardrail and its ability to contain the impacting vehicle.

The third test case involved a 4500 lb vehicle impacting the transition at 60 mph and 25 degrees. The primary objective of this test was to prevent severe decelerations to the vehicle and occupant by minimizing the amount of wheel contact on the end of the rigid bridge rail. For this test condition, the critical impact location was selected by varying the impact point along the transition. The critical impact location was defined as the point which maximized the potential for snagging on the bridge rail end.

The last impact scenario involved a 4500 lb vehicle traveling parallel to the primary roadway impacting at 60 mph and 0.0 degrees, with the centerline of the vehicle aligned with the guardrail. This test examined the potential for the vehicle to pocket or spear on the upstream end of the transition which is typically much stiffer than the guardrail to which it is attached. The major design parameters investigated with the simulation program included guardrail beam strength, post strength, post spacing, and runout length. Beam strength and stiffness were varied by using the properties of various common guardrail configurations including single, nested, and tubular W-beam and thrie beam. The primary objective was to find a rail that would be strong enough to contain a large car without imparting excessive decelerations to the small car. Simulations indicated that a single W-beam in the curved section of the barrier would satisfy both of these criteria. A nested W-beam was originally predicted to be too stiff for the small car, with an estimated longitudinal occupant impact velocity exceeding 40 ft/sec. Although the analysis was known to be conservative, it was decided to initially use a single W-beam in the curved segment of the rail. A much stronger tubular W-beam rail was used in the transition to help limit dynamic deflections near the bridge end and thus minimize snagging on the end of the bridge rail.

The initial short radius design also incorporated several different types of posts. These included standard 7 in. diameter timber posts, and two types of weakened timber breakaway posts. It was evident from previous crash test results (2) that weakened posts should be used along the curved section of rail. The purpose of the weakened posts is to facilitate fracture and thus prevent vehicle ramping during headon impacts. The posts are weakened by drilling two 2.5 in. diameter holes through a 7 in. diameter round wood post. One hole is located 16 in. below grade and the other is located at the ground line. This type of weakened post is commonly referred to as a CRT post.

These CRT posts are positioned with the holes perpendicular to the rail so that in headon impacts they fail in bending about the weak axis prior to yielding the soil. To model this behavior in Barrier VII, the bending failure force was input as a shear failure force. To calculate the force at which the weakened posts would fail, a simple stress analysis was employed. Using the National Design Specification for Wood Construction (12), the design bending stress for southern yellow pine was found to be 2400 psi. A procedure outlined in ASTM Design Standard D-2899-86 (13) was used to convert this design bending stress into a 5 percent exclusion limit of ultimate bending stress. After incorporating a dynamic impact factor of 2.0, the average ultimate bending stress for southern yellow pine was calculated to be 10,132 psi with a standard deviation of 1519 psi. This computed stress was then used along with the properties of the weakened cross-section to calculate the failure moment of the post. This moment was then divided by the height of the applied load to determine the force at which the post would fail in bending.

Since these CRT posts are designed to fracture upon impact, they possess little energy absorbing capability about their weak axis. The spacing of the posts along the curve was, therefore, not a critical design variable and a standard post spacing of 6 ft-3 in. was selected.

Another problem identified by the simulations was the inability of the curved section of rail to adequately limit dynamic deflections during oblique impacts into the transition. In order to alleviate this problem, an in-line cable anchor assembly was used just upstream of the transition. This anchor incorporates a standard breakaway BCT timber post placed in a steel foundation tube. A cable runs from an anchor plate bolted to the back side of the W-beam to the base of the BCT post. During oblique impacts into the transition, the anchorage develops tension in the rail which aids in the redirection of the impacting vehicle. During headon impacts into the curved section of guardrail, the cable remains slack and the weakened post fails in bending at the ground line. Initially, a second in-line BCT type anchor was also used in the curved region of guardrail to facilitate the redirection and prevent pocketing of vehicles impacting at a shallow angle in the curved section. This anchor was later discarded during modifications to the system during the full-scale crash test program.

In addition to material properties, geometric characteristics of the design were also considered. The performance of the short radius system was found to be sensitive to the radius used in the curved segment of rail. Tighter radii stiffened the system and increased the occupant impact velocities and ridedown accelerations experienced by the small car. Larger radii extended the overall length of the system and increased dynamic deflections during large car impacts. In addition to the radius of the curve, the effects of runout length on barrier performance were also investigated. A sufficient distance along the secondary roadway must be maintained in order to provide proper anchorage for the system. After analyzing several different configurations, a radius of 14 ft-3 in. and a runout length of approximately 60 ft were selected. Since the traffic volumes on these secondary roadways is expected to be very low, a standard turndown end treatment with a 2 ft offset was used to provide anchorage for the system.

The initial design, shown in Figure A-1, satisfied the requirements imposed by the four design impact conditions discussed above. A summary of the simulation results corresponding to these design impacts is given below.

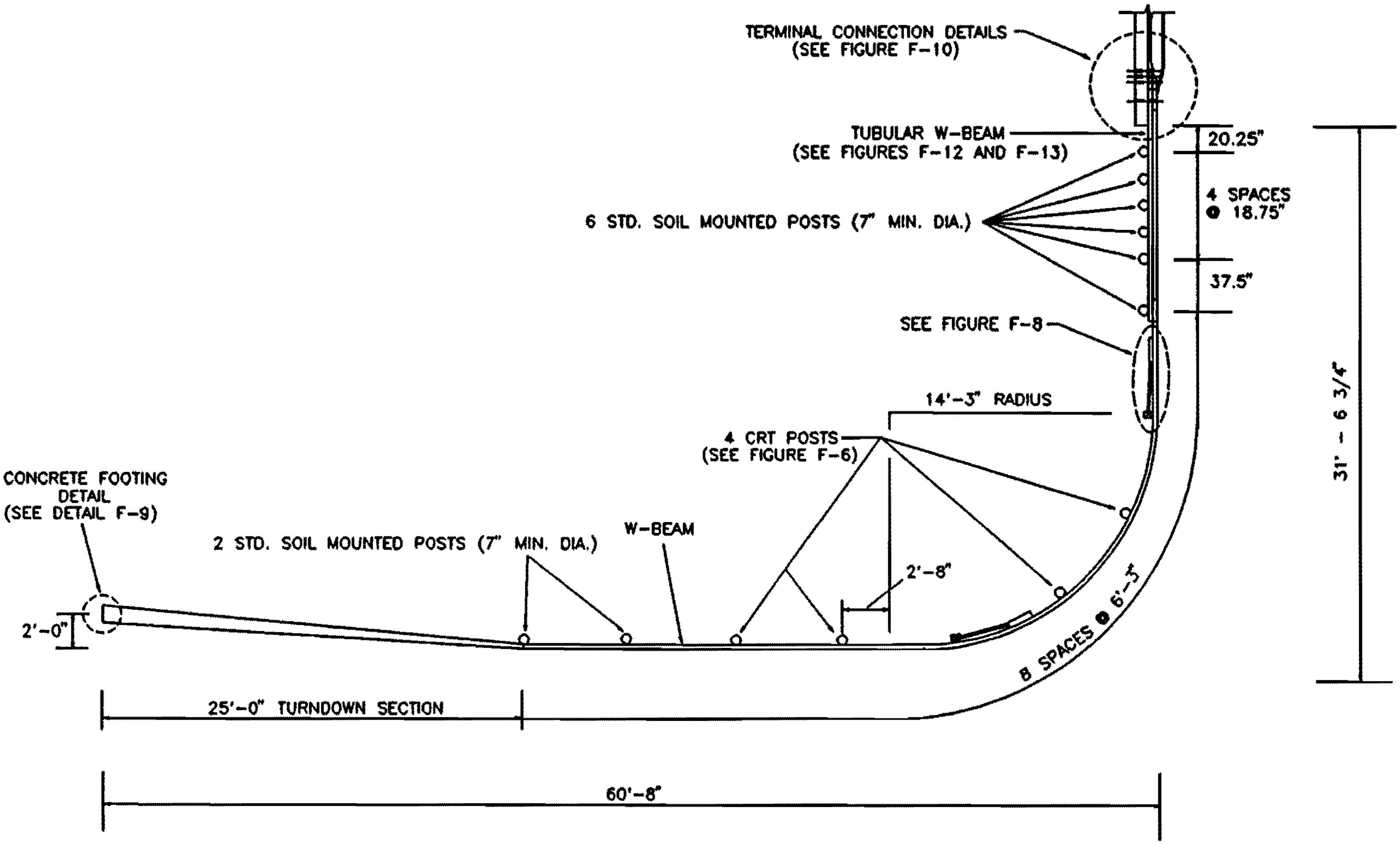


FIGURE A-1. Initial Short Radius Guardrail Design

Design Simulation 1: (1800 lb/20 deg/60 mph)

This simulation involved an 1800 lb vehicle impacting the midpoint of the curved portion of rail at a speed of 60 mph and at an angle of 20 degrees. The vehicle penetrated approximately 13.4 ft into the system, causing both 6" x 8" BCT posts and three CRT posts to fail in bending. Figure A-2 shows the predicted deflected barrier shape and resting position of the vehicle. Occupant impact velocities for this simulation were estimated to be 35.6 ft/sec and -6.6 ft/sec in the longitudinal and lateral directions, respectively. The highest 10-msec average occupant ridedown accelerations were predicted to be 9.3 g in the longitudinal direction and 3.0 g in the lateral direction. All of these occupant risk criteria are within the maximum allowable values outlined in NCHRP Report 230.

Design Simulation 2: (4500 lb/25 deg/60 mph)

This simulation involved a 4500 lb. vehicle impacting the midpoint of the curved part of the system at 60 mph and 25 degrees. Maximum dynamic rail deflection predicted for this impact scenario was 27.2 ft. The impact resulted in the failure used of both BCT posts and all four CRT posts in the curved section. Additionally, three standard posts were predicted to fail due to excessive rotation in the soil. Figure A-3 shows the estimated barrier shape and vehicle position after impact. In the longitudinal direction, occupant impact velocity was 21.9 ft/sec, and the highest 10-msec average ridedown acceleration was predicted to be 5.9 g. In the lateral direction, the occupant impact velocity was 0.4 ft/sec and the ridedown acceleration was estimated to be 1.5 g.

Design Simulation 3: (4500 lb/0 deg/60 mph)

This simulation involved a 4500 lb. vehicle impacting parallel to the primary road at speed of 60 mph and an angle of 0.0 degrees. The centerline of the vehicle was aligned with the rail parallel to the primary road causing the initial vehicle contact to occur in the curved section of the barrier. As shown in Figure A-4, the simulated vehicle penetrated approximately 9 ft into the system before slowing and yawing away from the beginning of the tubular W-beam transition. Damage to the installation was predicted to include fracture of the 6 in. x 8 in. BCT post at the upstream end of the transition and two CRT posts in the curved segment of rail. In addition, one standard post was predicted to fail in deflection

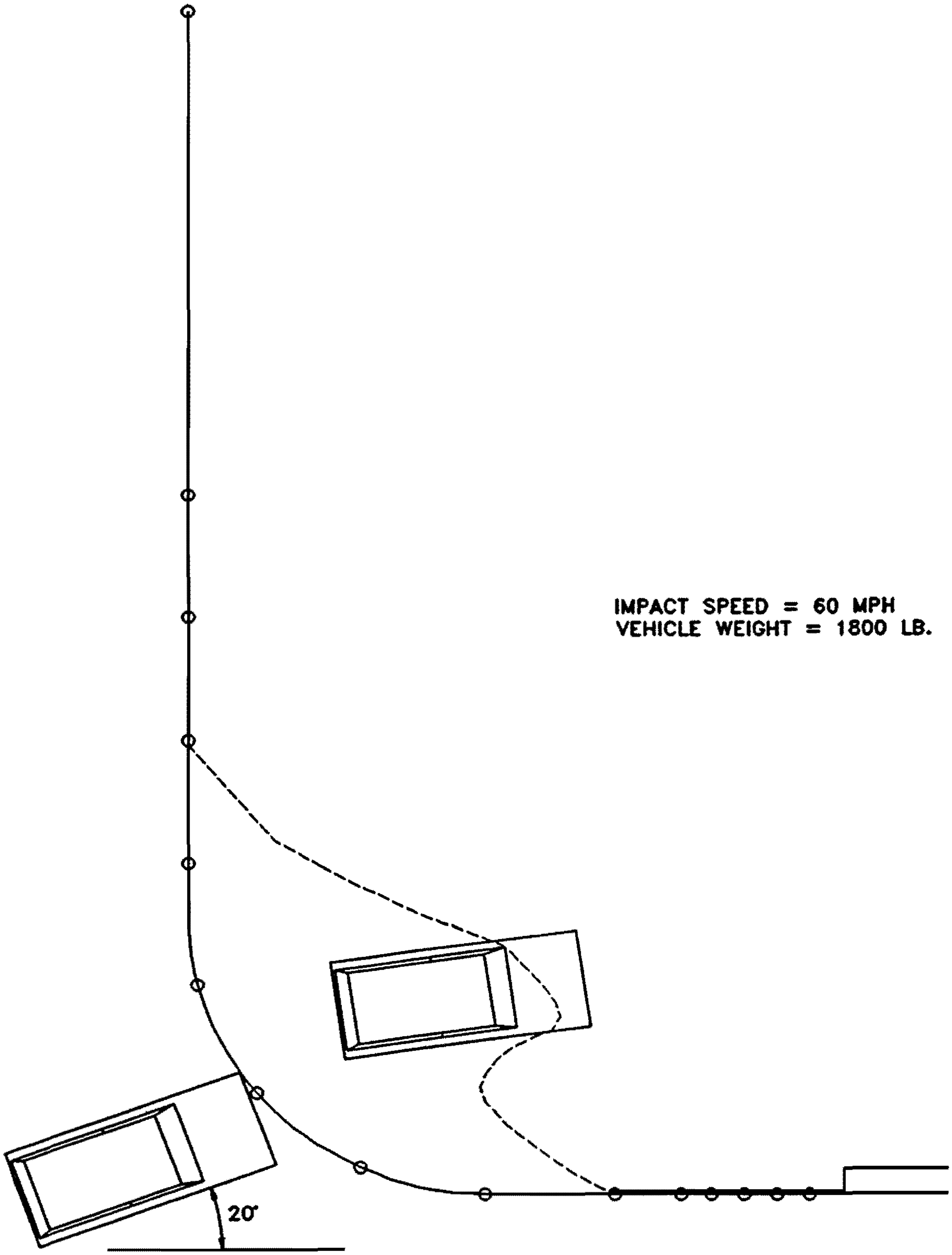


FIGURE A-2. Results of Design Simulation 1

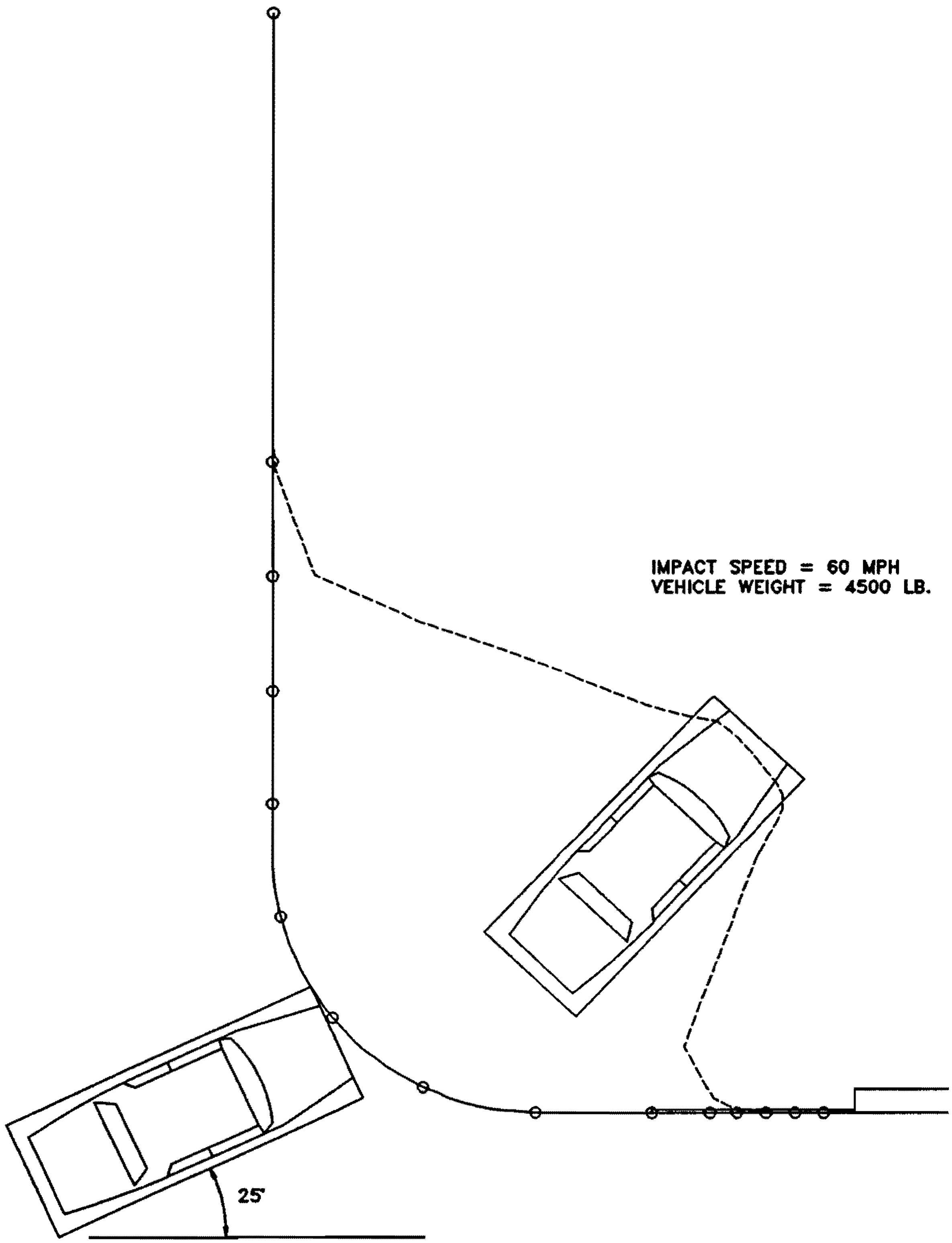


FIGURE A-3. Results of Design Simulation 2

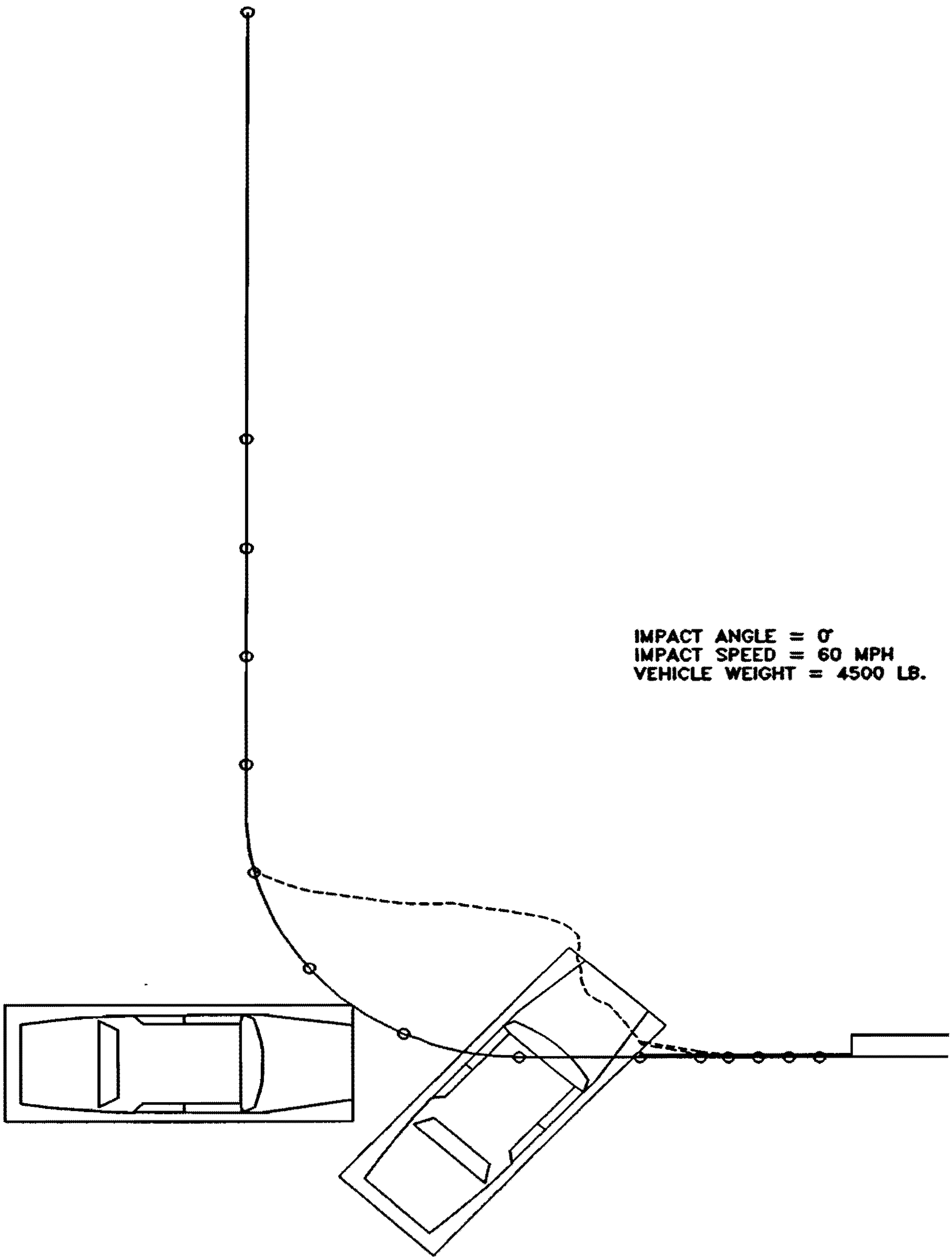


FIGURE A-4. Results of Design Simulation 3

after yielding the soil. Occupant impact velocities for this simulation were estimated to be 35.4 ft/sec and 8.6 ft/sec in the longitudinal and lateral directions, respectively. The highest 10-msec average occupant ridedown accelerations were predicted to be 20.9 g in the longitudinal direction and 4.6 g in the lateral direction.

Design Simulation 4: (4500 lb/25 deg/60 mph)

This simulation modeled a 4500 lb vehicle impacting the tubular W-beam transition 75 in. upstream from the bridge end at 60 mph and 25 degrees. This impact location was determined by Barrier VII to be the most critical in terms of the potential for wheel snagging on the end of the bridge rail. The simulated vehicle was successfully redirected at an exit speed of 35 mph. The amount of wheel overlap on the end of the rigid parapet was predicted to be 2 in. This amount of contact was judged to be acceptable considering the fact the contact would primarily involve the tire of the vehicle, exclusive of the wheel assembly.

In the longitudinal direction, occupant impact velocity was predicted to be 37.9 ft/sec. In the lateral direction, the occupant impact velocity and ridedown acceleration were estimated to be 21.3 ft/sec and 18.1 g, respectively.

The Barrier VII data sets that were used in the initial development and analysis of the short radius system differed only with the type and position of the vehicle. A typical set of input for the initial barrier design is listed in Figure A-5. It should be noted that deficiencies identified during the full-scale crash test program necessitated modifications to this initial concept. Details of these changes and their relevance to the impact behavior of the design are discussed in the main body of the report.

```
1BARRIER VII  -  ANALYSIS OF AUTOMOBILE BARRIERS  -  U.C. BERKELEY, 1972

 ************************************************************************

0CONTROL INFORMATION

 NUMBER OF BARRIER NODES              =    90
 NUMBER OF CONTROL NODES              =    39
 NUMBER OF NODE GENERATIONS           =     4

 NUMBER OF INTERFACES                 =     1

 NUMBER OF MEMBERS                    =   106
 NUMBER OF MEMBER GENERATIONS         =    21
 NUMBER OF DIFFERENT MEMBER SERIES    =     3

 NUMBER  OF ADDITIONAL WEIGHT SETS    =     0

0BASIC TIME STEP (SEC)                =    .00100
 LARGEST ALLOWABLE TIME STEP (SEC)    =    .00100
 MAXIMUM TIME SPECIFIED (SEC)         =    .40000
 MAX. NO. OF STEPS WITH NO CONTACT    =   100

 OVERSHOOT INDEX                      =     0
 ROTATIONAL DAMPING MULTIPLIER        =  1.00

 STEP-BY-STEP INTEGRATION TYPE        =     1



 OUTPUT FREQUENCIES

 AUTOMOBILE DATA      =  1
 BARRIER DEFLECTIONS  = 10
 BARRIER FORCES       = 10

 ENERGY BALANCE       = 10

 CONTACT INFORMATION  =  0

 PUNCHED JOINT DATA   =  0
 PUNCHED TRAJECTORY   =  0
1CONTROL NODE COORDINATES (IN)

 NODE         X-ORD         Y-ORD

    1           .00        403.13
    9           .00        253.13
   36           .00           .00
   37           .07         -5.49
   38           .71        -14.95
   39          1.68        -24.25
   40          3.28        -33.71
   41          5.26        -42.67
   42          5.26        -42.67
   43          7.95        -51.48
   44         11.20        -60.67
   45         14.65        -69.10
   46         18.68        -77.72
   47         23.28        -85.95
   48         28.26        -93.81
```

FIGURE A-5. Typical Barrier VII Input

49	33.43	-101.66
50	39.18	-108.94
51	45.51	-116.03
52	51.83	-122.92
53	58.93	-129.94
54	66.27	-134.99
55	73.73	-140.78
56	81.73	-145.47
57	90.01	-150.16
58	98.29	-154.58
59	108.85	-158.44
60	115.41	-161.75
61	124.52	-164.51
62	133.35	-166.99
63	142.74	-168.65
64	152.13	-169.75
65	161.79	-170.30
66	171.00	-171.00
67	171.00	-171.00
68	180.37	-171.00
75	246.00	-171.00
79	283.50	-171.00
89	377.25	-171.00
90	437.25	-171.00

COORDINATE GENERATION COMMANDS

FIRST NODE	LAST NODE	NO. OF NODES	NODE DIFF	DISTANCE
1	9	7	1	.00
9	36	26	1	.00
68	75	6	1	.00
75	89	13	1	.00

1NODE COORDINATES (IN)

NODE	X-ORD	Y-ORD
1	.00	403.13
2	.00	384.38
3	.00	365.63
4	.00	346.88
5	.00	328.13
6	.00	309.38
7	.00	290.63
8	.00	271.88
9	.00	253.13
10	.00	243.75
11	.00	234.38
12	.00	225.00
13	.00	215.63
14	.00	206.25
15	.00	196.88
16	.00	187.50
17	.00	178.13
18	.00	168.75
19	.00	159.38
20	.00	150.00
21	.00	140.63
22	.00	131.25
23	.00	121.88
24	.00	112.50
25	.00	103.13

FIGURE A-5. Typical Barrier VII Input (Con't)

26	.00	93.75
27	.00	84.38
28	.00	75.00
29	.00	65.63
30	.00	56.25
31	.00	46.88
32	.00	37.50
33	.00	28.13
34	.00	18.75
35	.00	9.38
36	.00	.00
37	.07	-5.49
38	.71	-14.95
39	1.68	-24.25
40	3.28	-33.71
41	5.26	-42.67
42	5.26	-42.67
43	7.95	-51.48
44	11.20	-60.67
45	14.65	-69.10
46	18.68	-77.72
47	23.28	-85.95
48	28.26	-93.81
49	33.43	-101.66
50	39.18	-108.94
51	45.51	-116.03
52	51.83	-122.92
53	58.93	-129.94
54	66.27	-134.99
55	73.73	-140.78
56	81.73	-145.47
57	90.01	-150.16
58	98.29	-154.58
59	108.85	-158.44
60	115.41	-161.75
61	124.52	-164.51
62	133.35	-166.99
63	142.74	-168.65
64	152.13	-169.75
65	161.79	-170.30
66	171.00	-171.00
67	171.00	-171.00
68	180.37	-171.00
69	189.75	-171.00
70	199.12	-171.00
71	208.50	-171.00
72	217.87	-171.00
73	227.25	-171.00
74	236.62	-171.00
75	246.00	-171.00
76	255.38	-171.00
77	264.75	-171.00
78	274.13	-171.00
79	283.50	-171.00
80	292.88	-171.00
81	302.25	-171.00
82	311.63	-171.00
83	321.00	-171.00
84	330.38	-171.00
85	339.75	-171.00
86	349.13	-171.00
87	358.50	-171.00
88	367.88	-171.00
89	377.25	-171.00
90	437.25	-171.00

FIGURE A-5. Typical Barrier VII Input (Con't)

```
1CONTACT INTERFACES


 INTERFACE  1

 NO. OF NODES =  60,  FRICTION COEFF. =  .300

 LIST OF NODES
          90       89       88       87       86       85       84       83       82       81
          80       79       78       77       76       75       74       73       71       70
          69       68       66       64       63       62       61       60       59       58
          57       56       55       54       53       52       51       50       49       48
          47       46       45       44       43       41       40       39       38       37
          36       35       34       33       32       31       30       29       28       27
1BEAM ELEMENTS, 100 SERIES


 TYPE NUMBER                  =          1          2          3          4          5
 M. OF I. (IN4)               =  2.330E+00  2.330E+00  1.000E+03  1.642E+01  2.330E+00
 AREA (IN2)                   =  1.990E+00  1.990E+00  1.000E+03  3.980E+00  1.990E+00
 LENGTH (IN)                  =  1.875E+01  9.375E+00  6.000E+01  9.375E+00  5.500E+00
 YOUNGS MODULUS (KSI)         =  3.000E+04  3.000E+04  3.000E+04  3.000E+04  3.000E+04
 WEIGHT (LB/FT)               =  6.770E+00  6.770E+00  1.000E+04  1.353E+01  6.770E+00
 YIELD FORCE (K)              =  9.950E+01  9.950E+01  1.000E+04  1.990E+02  9.950E+01
 YIELD MOMENT (K.IN)          =  6.850E+01  6.850E+01  1.000E+04  2.525E+02  6.850E+01
 YIELD ACCURACY LIMIT         =  1.000E-01  1.000E-01  1.000E-01  1.000E-01  1.000E-01
1CABLE ELEMENTS, 200 SERIES


 TYPE NUMBER                  =          1
 AREA (IN2)                   =  4.420E-01
 LENGTH (IN)                  =  4.800E+01
 YOUNGS MODULUS (KSI)         =  1.200E+04
 WEIGHT (LB/FT)               =  9.000E-01
 YIELD FORCE (K)              =  1.000E+04
 YIELD ACCURACY LIMIT         =  1.000E-01
1POSTS, 300 SERIES


 TYPE NUMBER                  =          1          2          3          4          5          6
 HEIGHT OF NODE I (IN)        =  2.100E+01  2.100E+01  2.100E+01  2.100E+01  2.100E+01  2.100E+01
 HEIGHT OF NODE J (IN)        =   .000E+00   .000E+00   .000E+00   .000E+00  3.000E+00  3.000E+00
 A AXIS STIFFNESS (K/IN)      =  1.000E+04  2.900E+00  2.900E+00  1.500E+03  4.550E+00  3.560E+00
 B AXIS STIFFNESS (K/IN)      =  1.000E+04  2.900E+00  2.900E+00  1.500E+03  3.560E+00  4.550E+00
 EFFECTIVE WEIGHT (LB)        =  1.000E+02  5.100E+01  5.100E+01  5.100E+01  5.100E+01  5.100E+01
 B AXIS YIELD MOMENT (K.IN)   =  1.000E+04  1.000E+04  2.560E+02  1.000E+04  1.000E+04  1.000E+04
 A AXIS YIELD MOMENT (K.IN)   =  1.000E+04  1.000E+04  2.560E+02  1.000E+04  2.560E+02  2.140E+02
 YIELD ACCURACY LIMIT         =  1.000E-01  1.000E-01  1.000E-01  1.000E-01  1.000E-01  1.000E-01
 A SHEAR AT FAILURE (K)       =  1.000E+04  1.963E+01  1.000E+04  1.000E+04  4.838E+01  4.838E+01
 B SHEAR AT FAILURE (K)       =  1.000E+04  8.370E+00  1.000E+04  1.000E+04  3.861E+01  5.431E+01
 A DEFLN AT FAILURE (IN)      =  1.000E+04  2.000E+01  2.000E+01  1.000E+04  2.710E+00  3.930E+00
 B DEFLN AT FAILURE (IN)      =  1.000E+04  2.000E+01  2.000E+01  1.000E+04  6.520E+00  3.660E+00
1MEMBER GENERATION COMMANDS

  FIRST     NODE     NODE    LAST      NODE     TYPE                             PRESTRESS DATA
 MEMBER      I        J     MEMBER     DIFF      NO.             1            2            3            4
5

    1        1        2        8         1      101            .000         .000         .000         .000
.000
    9        9       10       35         1      102            .000         .000         .000         .000
.000
   36       36       37        0         0      105            .000         .000         .000         .000
.000
```

FIGURE A-5. Typical Barrier VII Input (Con't)

37	37	38	39	1	102	.000	.000	.000	.000	.000
40	40	42	0	2	102	.000	.000	.000	.000	.000
41	42	43	63	1	102	.000	.000	.000	.000	.000
64	65	67	0	2	102	.000	.000	.000	.000	.000
65	67	68	72	1	102	.000	.000	.000	.000	.000
73	75	76	86	1	104	.000	.000	.000	.000	.000
87	89	90	0	0	103	.000	.000	.000	.000	.000
88	42	47	0	0	201	.010	.000	.000	.000	.000
89	67	72	0	0	201	.010	.000	.000	.000	.000
90	1	0	0	0	304	.000	.000	.000	.000	.000
91	9	0	92	8	303	.000	.000	.000	.000	.000
93	25	0	94	8	302	.000	.000	.000	.000	.000
95	41	42	0	0	306	.000	.000	.000	.000	.000
96	50	0	97	8	302	.000	.000	.000	.000	.000
98	66	67	0	0	305	.000	.000	.000	.000	.000
99	75	0	0	0	303	.000	.000	.000	.000	.000
100	79	0	104	2	303	.000	.000	.000	.000	.000
105	89	0	106	1	301	.000	.000	.000	.000	.000

1COMPLETE MEMBER DATA

BEAMS, 100 SERIES

MEMBER	NODE I	NODE J	TYPE	FORCE	I-MOMENT	J-MOMENT
1	1	2	101	.00	.00	.00
2	2	3	101	.00	.00	.00
3	3	4	101	.00	.00	.00
4	4	5	101	.00	.00	.00
5	5	6	101	.00	.00	.00
6	6	7	101	.00	.00	.00
7	7	8	101	.00	.00	.00
8	8	9	101	.00	.00	.00
9	9	10	102	.00	.00	.00
10	10	11	102	.00	.00	.00
11	11	12	102	.00	.00	.00
12	12	13	102	.00	.00	.00
13	13	14	102	.00	.00	.00
14	14	15	102	.00	.00	.00
15	15	16	102	.00	.00	.00
16	16	17	102	.00	.00	.00
17	17	18	102	.00	.00	.00
18	18	19	102	.00	.00	.00
19	19	20	102	.00	.00	.00
20	20	21	102	.00	.00	.00
21	21	22	102	.00	.00	.00
22	22	23	102	.00	.00	.00

FIGURE A-5. Typical Barrier VII Input (Con't)

23	23	24	102	.00	.00	.00
24	24	25	102	.00	.00	.00
25	25	26	102	.00	.00	.00
26	26	27	102	.00	.00	.00
27	27	28	102	.00	.00	.00
28	28	29	102	.00	.00	.00
29	29	30	102	.00	.00	.00
30	30	31	102	.00	.00	.00
31	31	32	102	.00	.00	.00
32	32	33	102	.00	.00	.00
33	33	34	102	.00	.00	.00
34	34	35	102	.00	.00	.00
35	35	36	102	.00	.00	.00
36	36	37	105	.00	.00	.00
37	37	38	102	.00	.00	.00
38	38	39	102	.00	.00	.00
39	39	40	102	.00	.00	.00
40	40	42	102	.00	.00	.00
41	42	43	102	.00	.00	.00
42	43	44	102	.00	.00	.00
43	44	45	102	.00	.00	.00
44	45	46	102	.00	.00	.00
45	46	47	102	.00	.00	.00
46	47	48	102	.00	.00	.00
47	48	49	102	.00	.00	.00
48	49	50	102	.00	.00	.00
49	50	51	102	.00	.00	.00
50	51	52	102	.00	.00	.00
51	52	53	102	.00	.00	.00
52	53	54	102	.00	.00	.00
53	54	55	102	.00	.00	.00
54	55	56	102	.00	.00	.00
55	56	57	102	.00	.00	.00
56	57	58	102	.00	.00	.00
57	58	59	102	.00	.00	.00
58	59	60	102	.00	.00	.00
59	60	61	102	.00	.00	.00
60	61	62	102	.00	.00	.00
61	62	63	102	.00	.00	.00
62	63	64	102	.00	.00	.00
63	64	65	102	.00	.00	.00
64	65	67	102	.00	.00	.00
65	67	68	102	.00	.00	.00
66	68	69	102	.00	.00	.00
67	69	70	102	.00	.00	.00
68	70	71	102	.00	.00	.00
69	71	72	102	.00	.00	.00
70	72	73	102	.00	.00	.00
71	73	74	102	.00	.00	.00
72	74	75	102	.00	.00	.00
73	75	76	104	.00	.00	.00
74	76	77	104	.00	.00	.00
75	77	78	104	.00	.00	.00
76	78	79	104	.00	.00	.00
77	79	80	104	.00	.00	.00
78	80	81	104	.00	.00	.00
79	81	82	104	.00	.00	.00
80	82	83	104	.00	.00	.00
81	83	84	104	.00	.00	.00
82	84	85	104	.00	.00	.00
83	85	86	104	.00	.00	.00
84	86	87	104	.00	.00	.00
85	87	88	104	.00	.00	.00
86	88	89	104	.00	.00	.00
87	89	90	103	.00	.00	.00

FIGURE A-5. Typical Barrier VII Input (Con't)

CABLES, 200 SERIES

MEMBER	NODE I	NODE J	TYPE	FORCE	SLACK
88	42	47	201	.01	.000
89	67	72	201	.01	.000

POSTS, 300 SERIES

MEMBER	NODE I	NODE J	TYPE	A-SHEAR	B-SHEAR	B-MOMENT	A-MOMENT	ANGLE
90	1	0	304	.00	.00	.00	.00	.00
91	9	0	303	.00	.00	.00	.00	.00
92	17	0	303	.00	.00	.00	.00	.00
93	25	0	302	.00	.00	.00	.00	.00
94	33	0	302	.00	.00	.00	.00	.00
95	41	42	306	.00	.00	.00	.00	.00
96	50	0	302	.00	.00	.00	.00	.00
97	58	0	302	.00	.00	.00	.00	.00
98	66	67	305	.00	.00	.00	.00	.00
99	75	0	303	.00	.00	.00	.00	.00
100	79	0	303	.00	.00	.00	.00	.00
101	81	0	303	.00	.00	.00	.00	.00
102	83	0	303	.00	.00	.00	.00	.00
103	85	0	303	.00	.00	.00	.00	.00
104	87	0	303	.00	.00	.00	.00	.00
105	89	0	301	.00	.00	.00	.00	.00
106	90	0	301	.00	.00	.00	.00	.00

STIFFNESS MATRIX STORAGE

REQUIRED = 4860
ALLOCATED = 6000
1AUTOMOBILE PROPERTIES

WEIGHT (LB)	=	4500.0
MOMENT OF INERTIA (LB.IN.SEC2)	=	47000.0
NO. OF CONTACT POINTS	=	19
NO. OF UNIT STIFFNESSES	=	2
NO. OF WHEELS	=	4
BRAKE CODE (1=ON, 0=OFF)	=	0
NO. OF OUTPUT POINTS	=	3

UNIT STIFFNESSES (K/IN/IN)

NO.	BEFORE BOTTOMING	AFTER BOTTOMING	UNLOADING	BOTTOMING DISTANCE
1	.040	.250	7.500	12.00
2	1.440	9.000	11.880	1.00

CONTACT POINT DATA

FIGURE A-5. Typical Barrier VII Input (Con't)

POINT	R COORD	S COORD	STIFFNESS NO.	TRIBUTARY LENGTH	INTERFACE CONTACTS			
1	57.00	31.00	2	1.00	0	0	0	0
2	57.00	-31.00	2	1.00	0	0	0	0
3	-122.00	40.00	1	31.00	1	0	0	0
4	-30.00	40.00	1	30.00	1	0	0	0
5	.00	40.00	1	27.00	1	0	0	0
6	23.00	40.00	1	23.00	1	0	0	0
7	46.00	40.00	1	23.00	1	0	0	0
8	69.00	40.00	1	23.00	1	0	0	0
9	93.00	40.00	1	22.00	1	0	0	0
10	93.00	20.00	1	20.00	1	0	0	0
11	93.00	.00	1	20.00	1	0	0	0
12	93.00	-20.00	1	20.00	1	0	0	0
13	93.00	-40.00	1	22.00	1	0	0	0
14	69.00	-40.00	1	23.00	1	0	0	0
15	46.00	-40.00	1	23.00	1	0	0	0
16	23.00	-40.00	1	23.00	1	0	0	0
17	.00	-40.00	1	27.00	1	0	0	0
18	-30.00	-40.00	1	30.00	1	0	0	0
19	-122.00	-40.00	1	31.00	1	0	0	0

0WHEEL COORDINATES (IN), STEER ANGLES (DEG), AND DRAG FORCES (LB)

POINT	R-ORD	S-ORD	STEER ANGLE	DRAG FORCE
1	57.00	31.00	.00	608.00
2	57.00	-31.00	.00	608.00
3	-67.00	31.00	.00	517.00
4	-67.00	-31.00	.00	517.00

0OUTPUT POINT COORDINATES (IN)

POINT	R-ORD	S-ORD
1	.00	.00
2	93.00	.00
3	57.00	31.00

1INITIAL POSITION AND VELOCITIES OF AUTO

SPECIFIED BOUNDARY POINT	=	9
X ORDINATE OF POINT	=	305.25
Y ORDINATE OF POINT	=	-171.00
ANGLE FROM X AXIS TO R AXIS (DEG)	=	25.00
VELOCITY IN R DIRECTION (M.P.H)	=	60.00
VELOCITY IN S DIRECTION (M.P.H)	=	.00
ANGULAR VELOCITY (RAD/SEC)	=	.000
MINIMUM RESULTANT VELOCITY (M.P.H)	=	.00
TRANSLATIONAL KINETIC ENERGY (K.IN)	=	6500.15
ROTATIONAL KINETIC ENERGY (K.IN)	=	.00
TOTAL INITIAL KINETIC ENERGY (K.IN)	=	6500.15

FIGURE A-5. Typical Barrier VII Input (Con't)

APPENDIX B

SEVERITY INDEX CURVES AND BENEFIT-COST PROGRAM INPUT

SEVERITY INDEX CURVES AND BENEFIT-COST PROGRAM INPUT

Severity Index Curves

A family of severity index versus impact speed curves for a range of impact angles were constructed for each of the nine options considered in the B/C analysis. A discussion of the methodology used in determining these curves is given in Section 4.3. The curves are given in Figures B-1 through B-59.

As appropriate, each graph has curves for impacts at 5, 15, 25, 35, and 45 deg for both the 1,800 lb and 4,500 lb design vehicles. Dashed lines refer to the 1,800 lb vehicle and solid lines refer to the 4, 500 lb vehicle. In some cases, such as the untreated bridge end (Hazard #1 of Figure B-57), it is assumed the severity index is independent of impact angle.

Input Data for B/C Program

A complete set of input data for each of the nine options evaluated by the B/C program is given at the end of this appendix. Note that the first eight lines of the input contain setup data for the program, including number of options, output options, functional class of roadway, ADT, severity index versus societal cost data, etc.

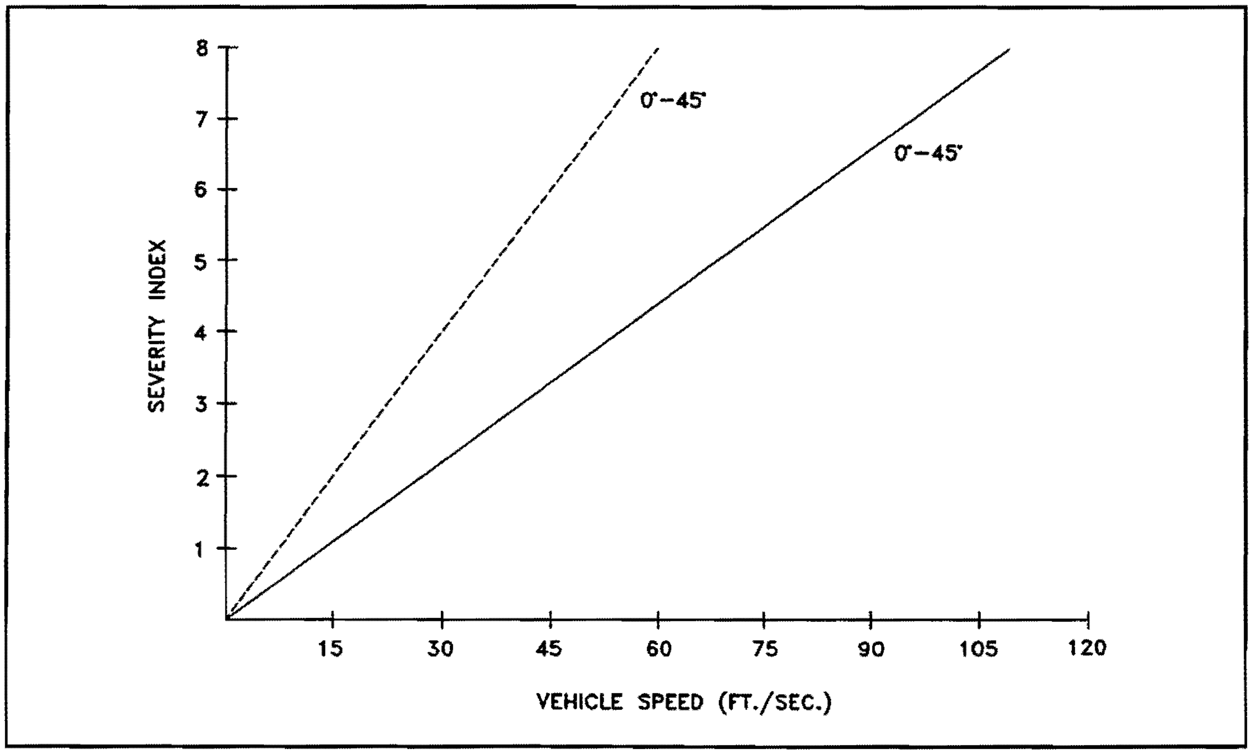


FIGURE B-1. Severity Curve for 45 mph Short Radius Nested W-Beam System: Hazard #1 (12.5 Ft. Turndown)

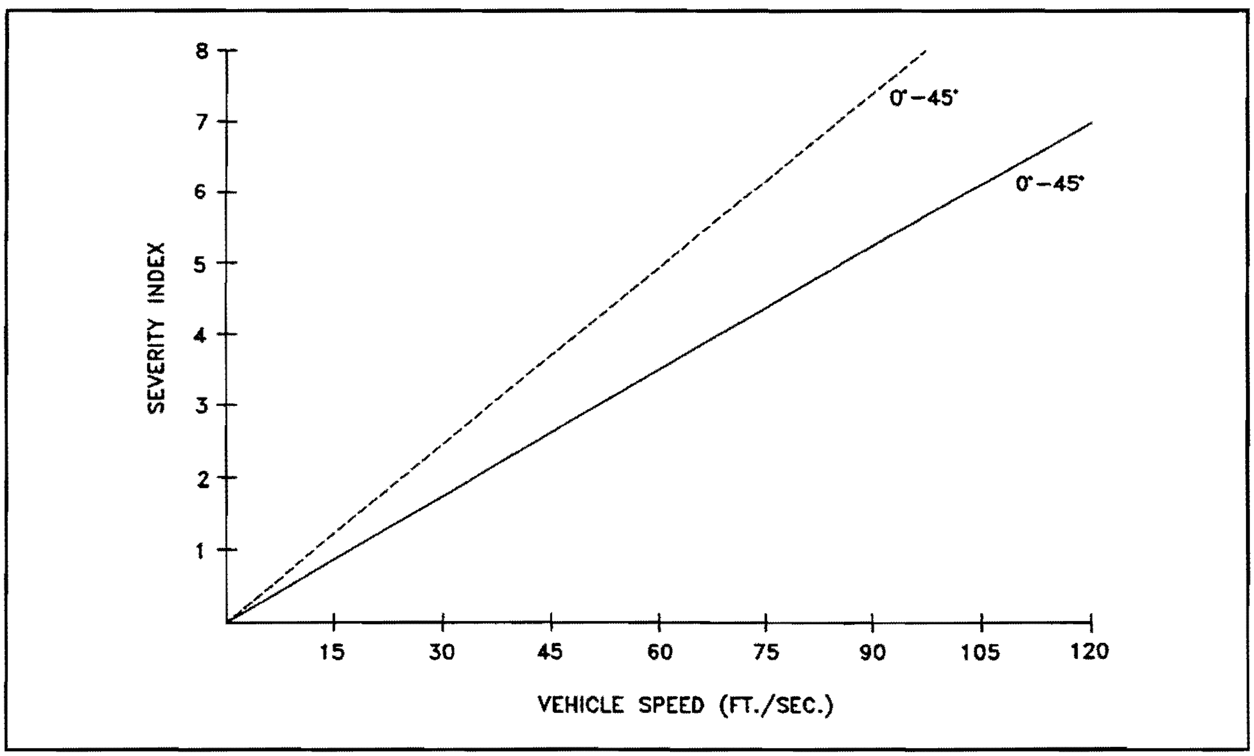


FIGURE B-2. Severity Curve for 45 mph Short Radius Nested W-Beam System: Hazard #2 (Rail Between Curve and Turndown)

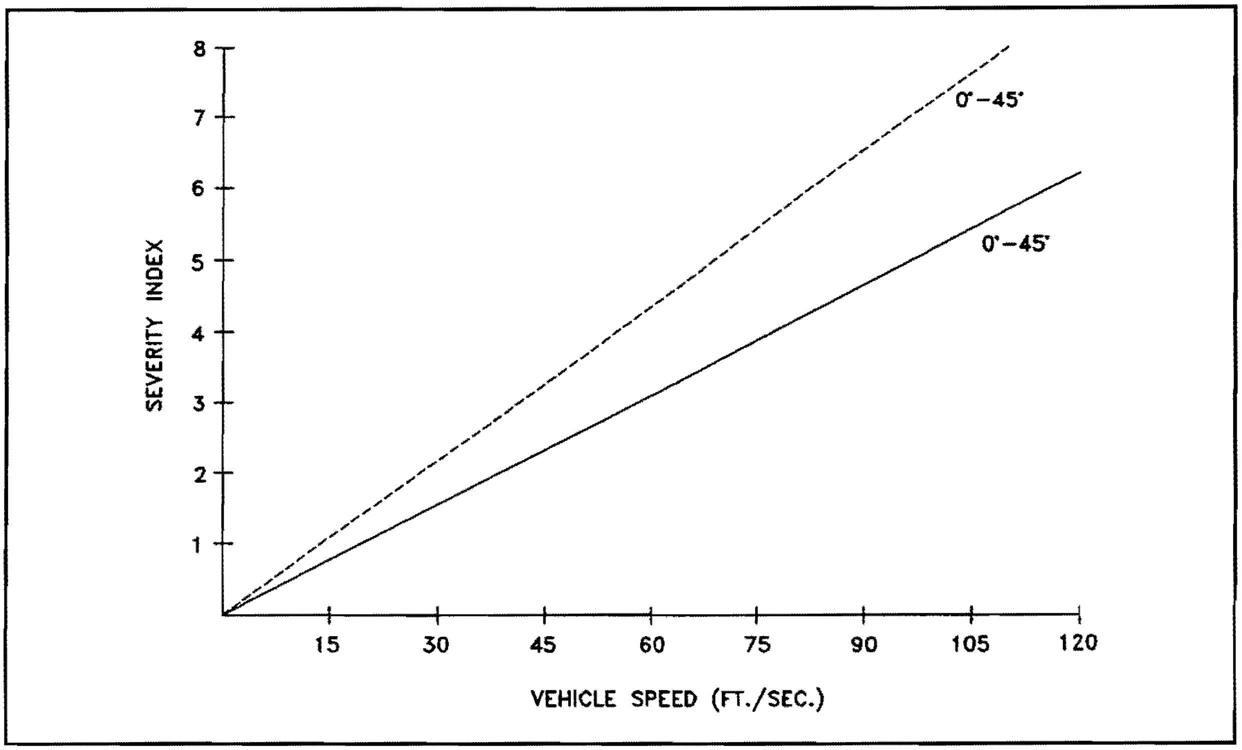


FIGURE B-3. Severity Curve for 45 mph Short Radius Nested W-Beam System: Hazard #3 (Rail Between Upstream Posts in Curve)

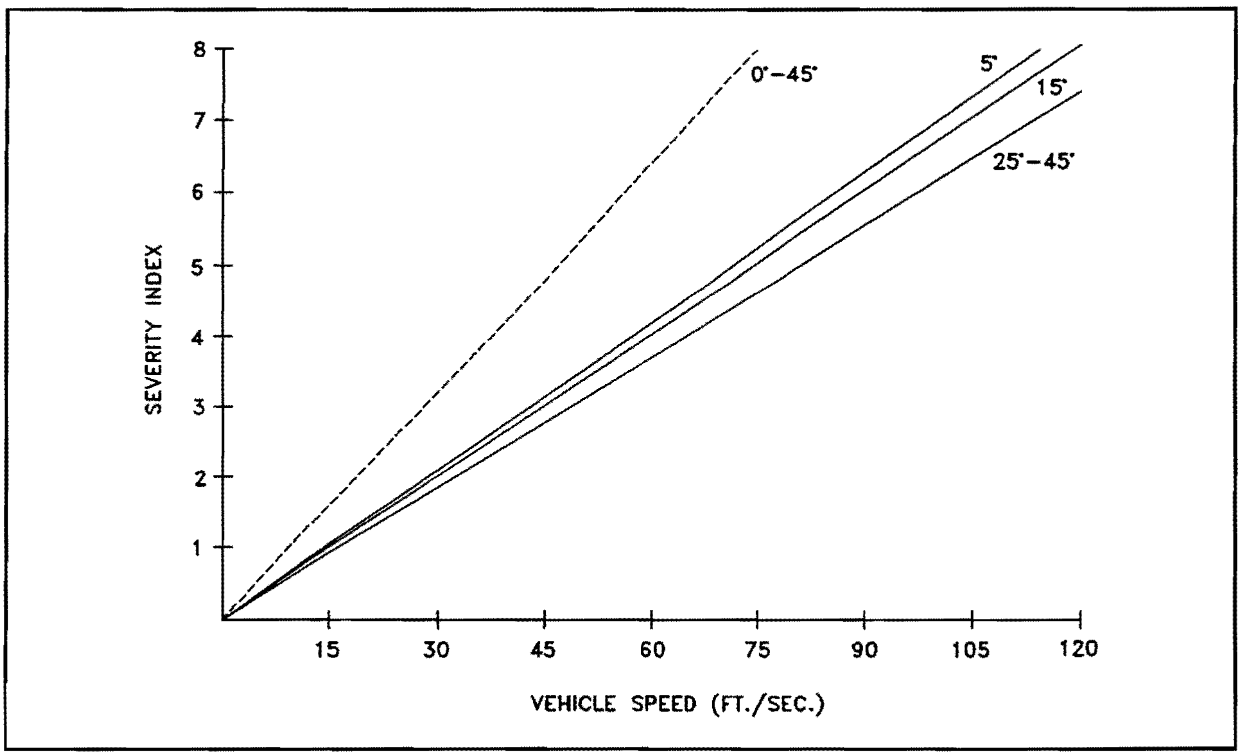


FIGURE B-4. Severity Curve for 45 mph Short Radius Nested W-Beam System: Hazard #4 (Rail Between Middle Posts in Curve)

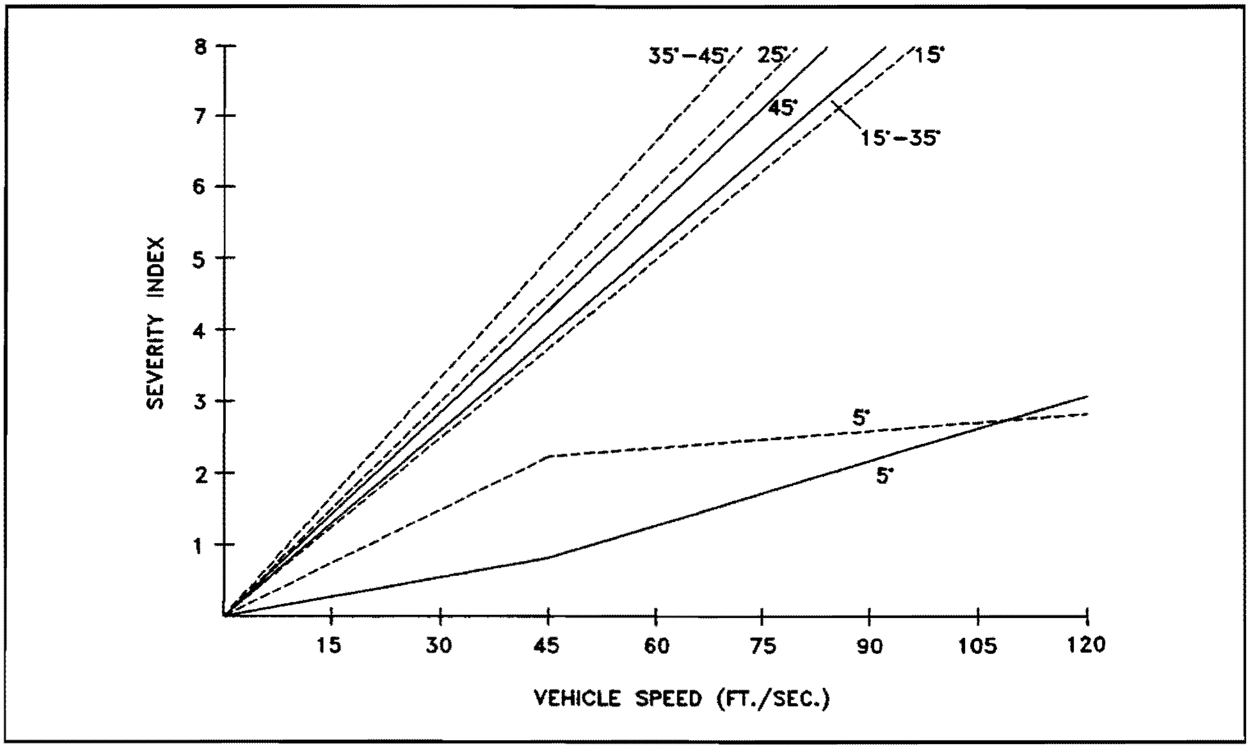


FIGURE B-5. Severity Curve for 45 mph Short Radius Nested W-Beam System: Hazard #5 (Rail Between Last Posts in Curve)

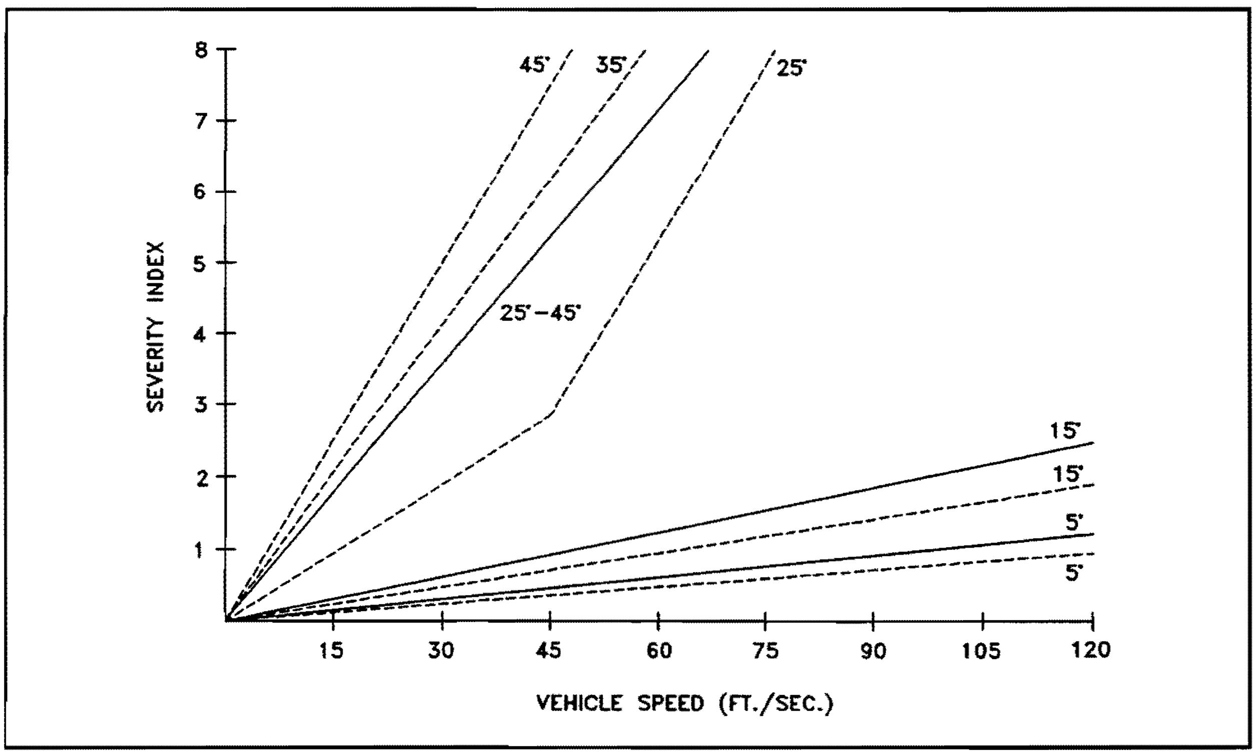


FIGURE B-6. Severity Curve for 45 mph Short Radius Nested W-Beam System: Hazard #6 (6.25 ft Transition)

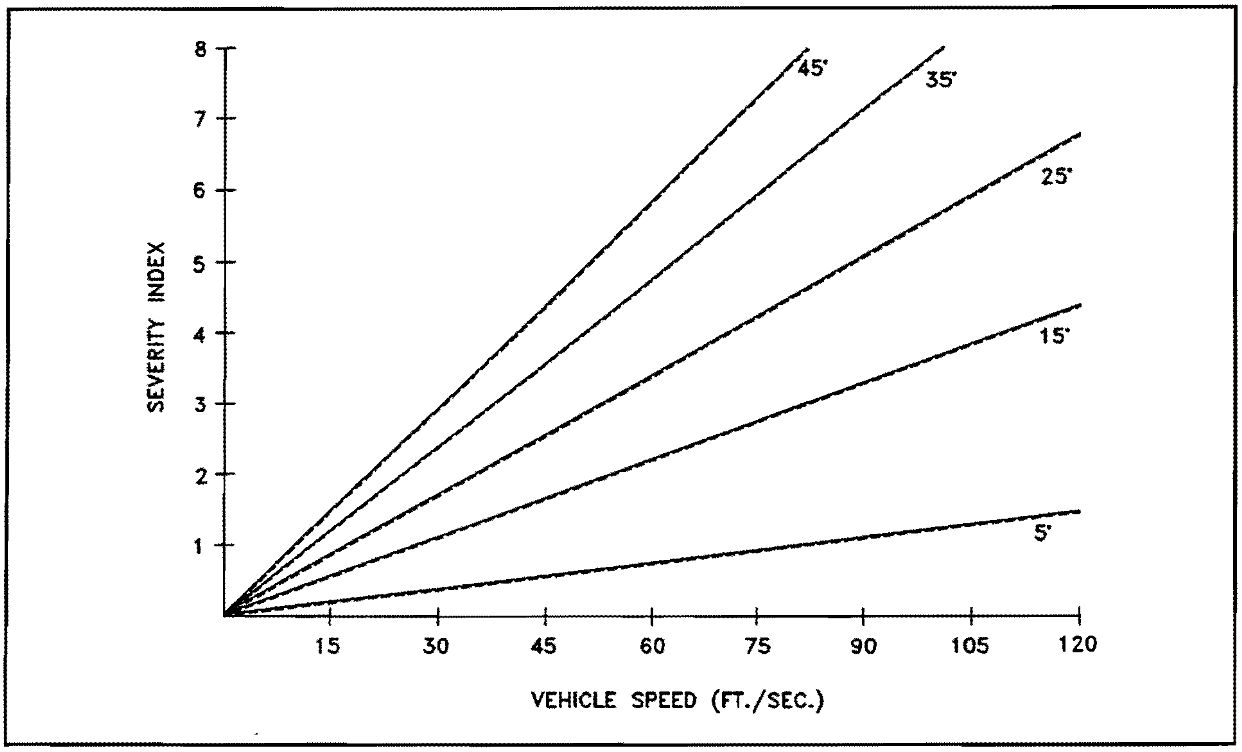


FIGURE B-7. Severity Curve for 45 mph Short Radius Nested W-Beam System: Hazard #7 (Bridge Wall)

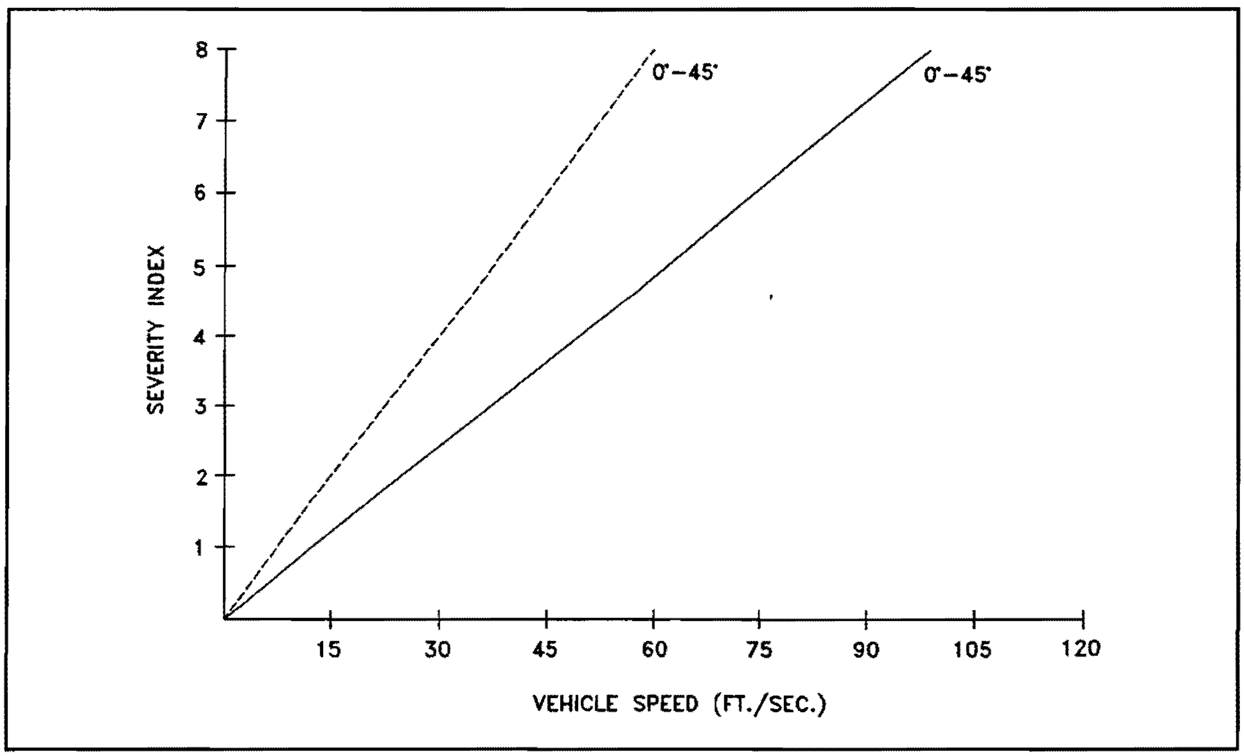


FIGURE B-8. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #1 (25 ft Turndown)

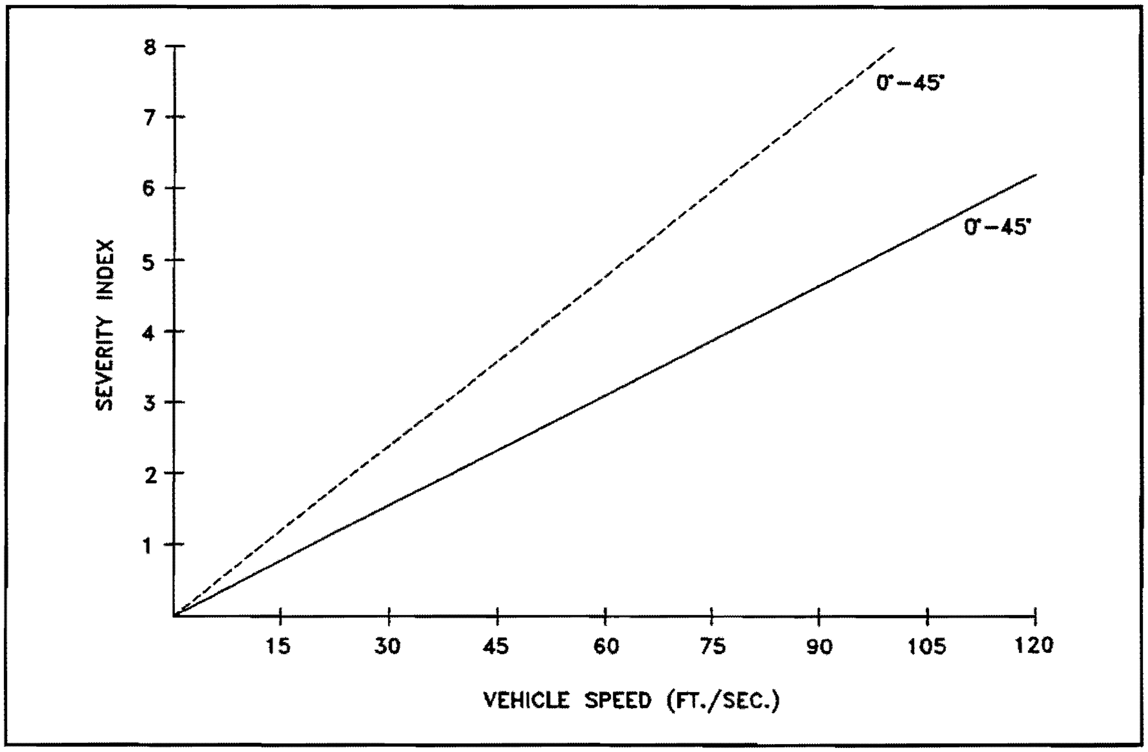


FIGURE B-9. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #2 (Rail Between Curve and Turndown)

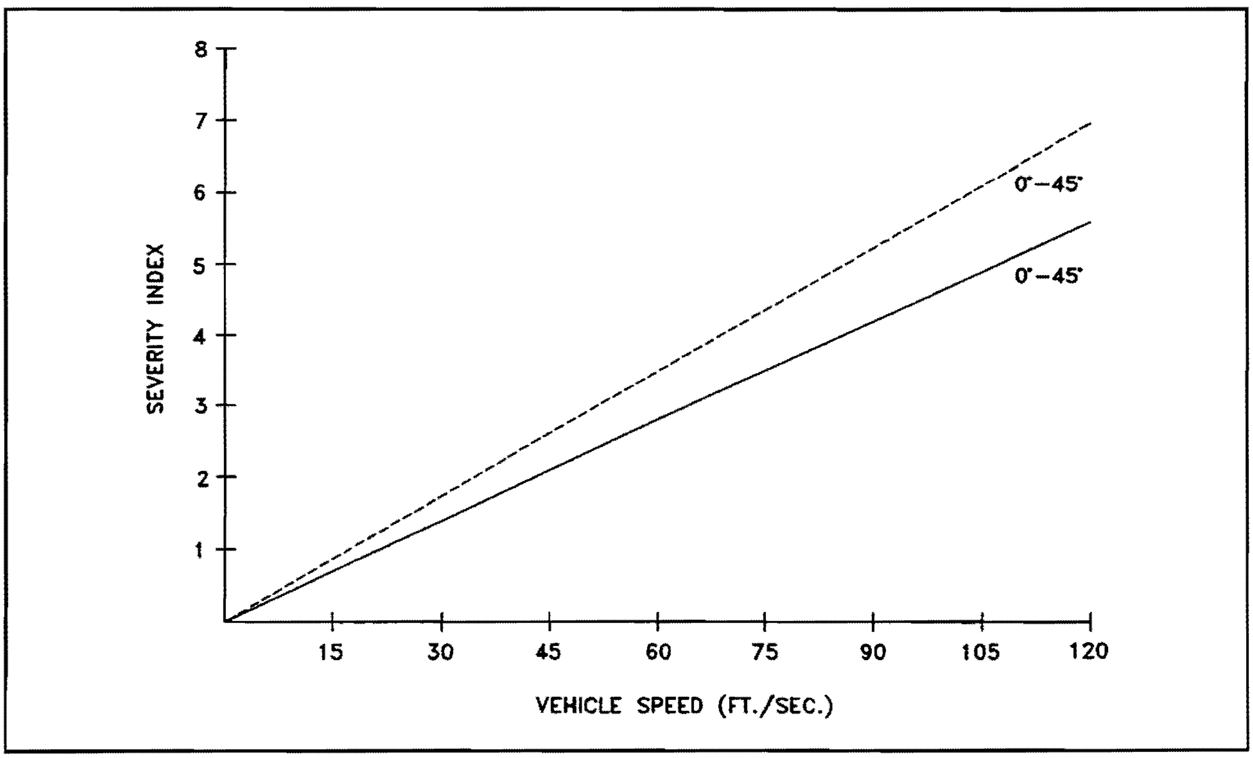


FIGURE B-10. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #3 (Rail Between Upstream Posts in Curve)

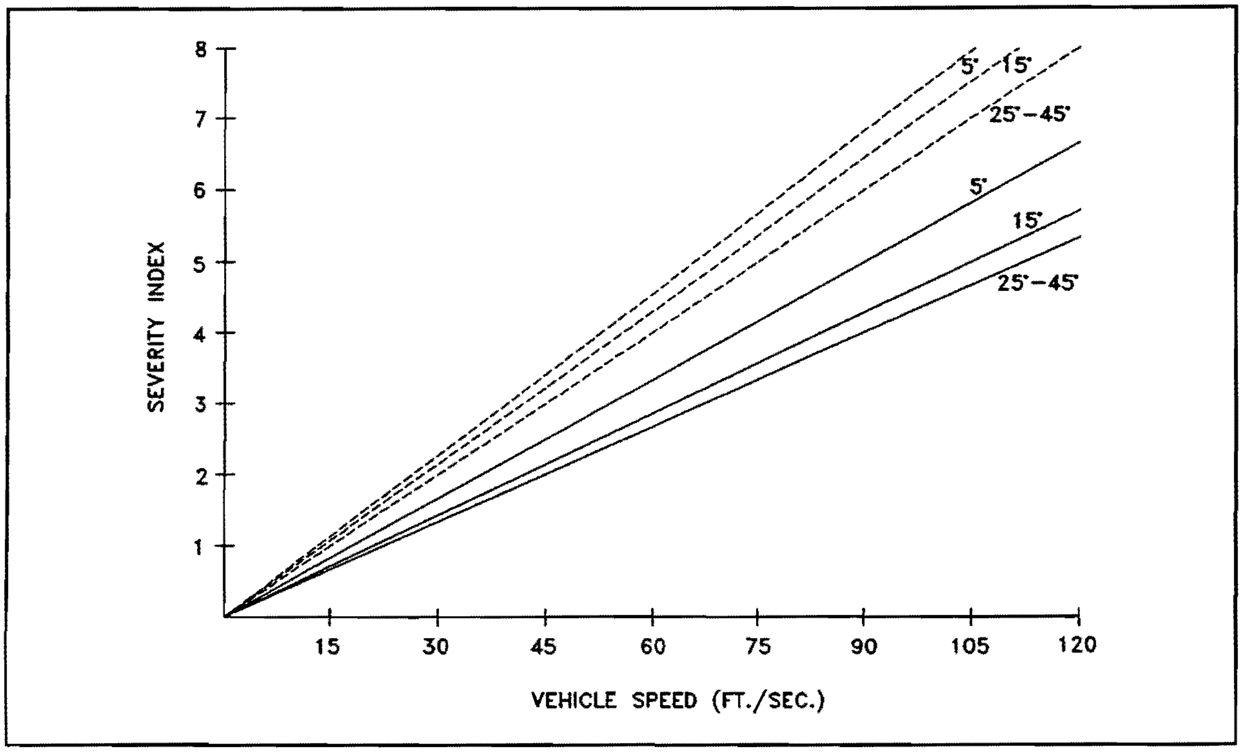


FIGURE B-11. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #4 (Rail Between Second Pair of Posts in Curve)

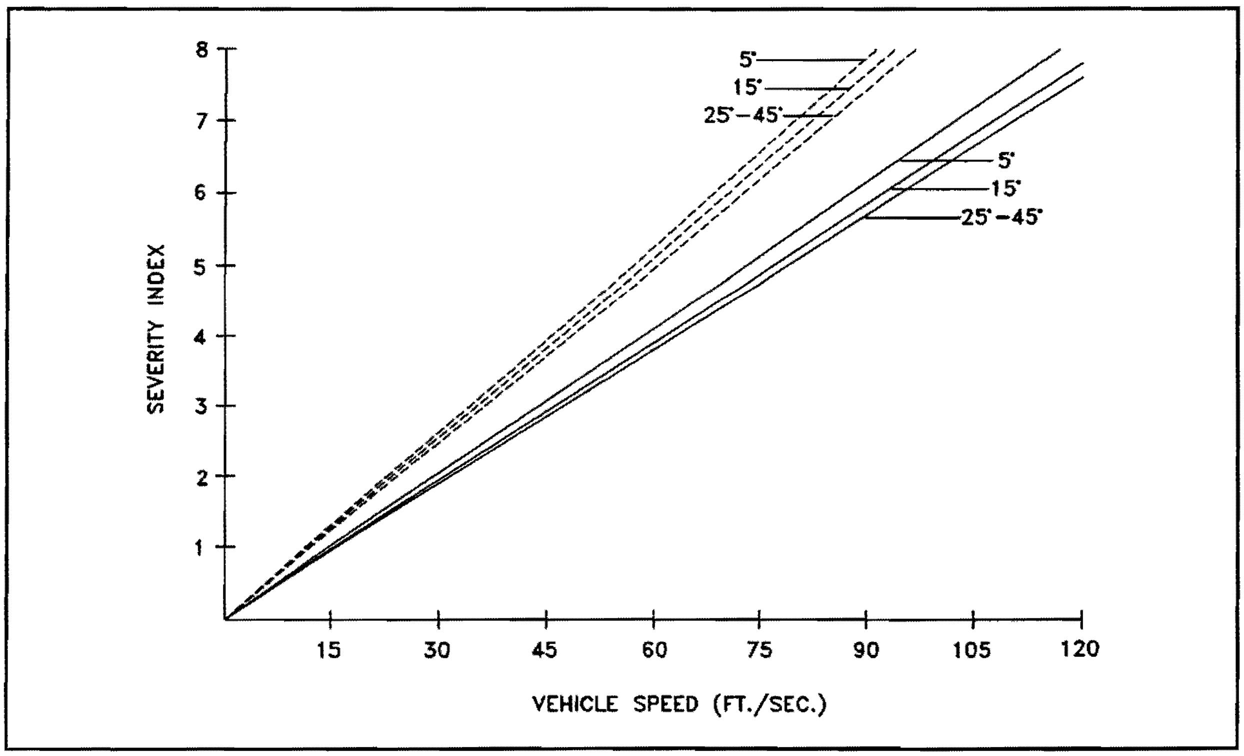


FIGURE B-12. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #5 (Rail Between Third Pair of Posts in Curve)

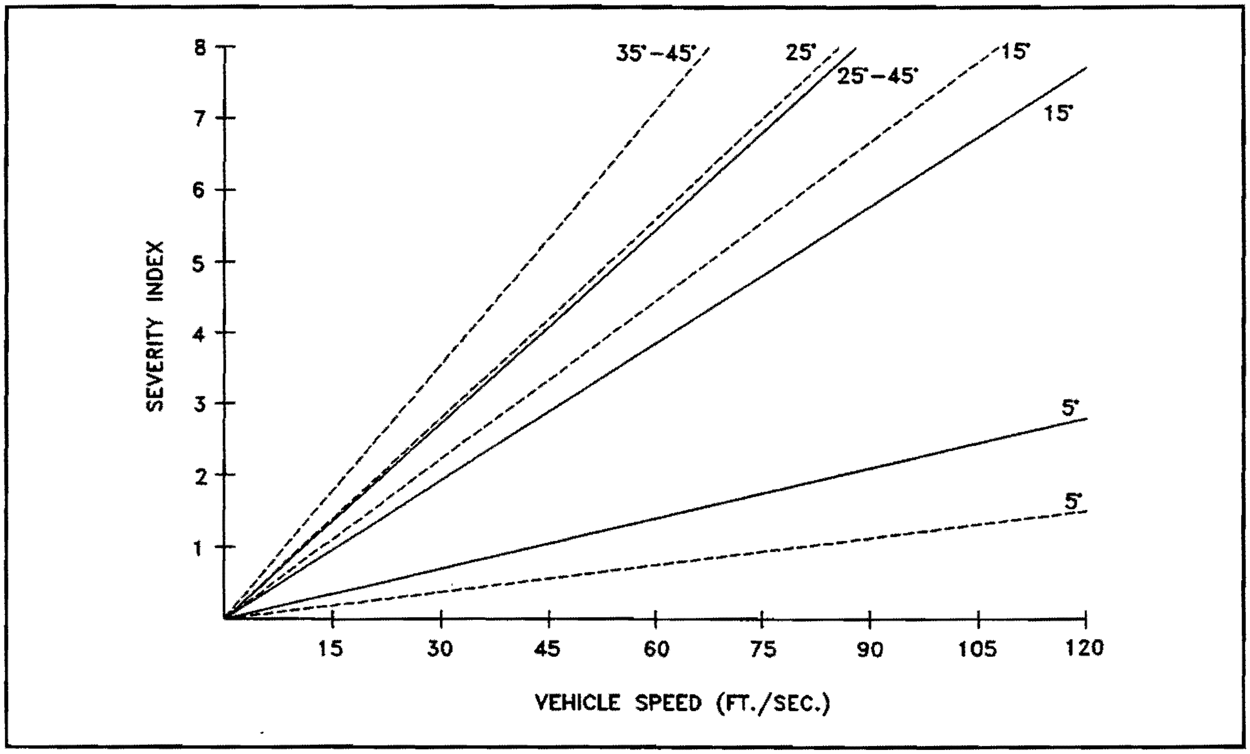


FIGURE B-13. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #6 (Rail Between Last Pair of Posts in Curve)

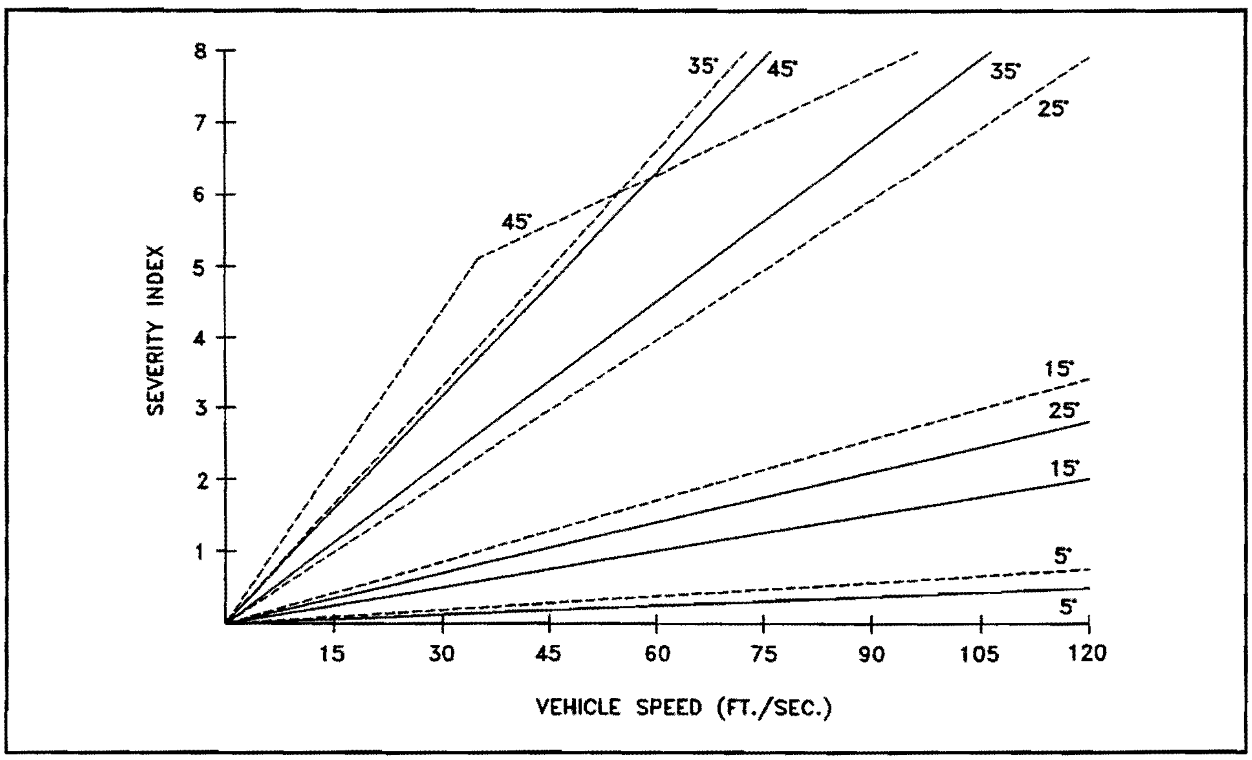


FIGURE B-14. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #7 (Rail Between Curve and Transition)

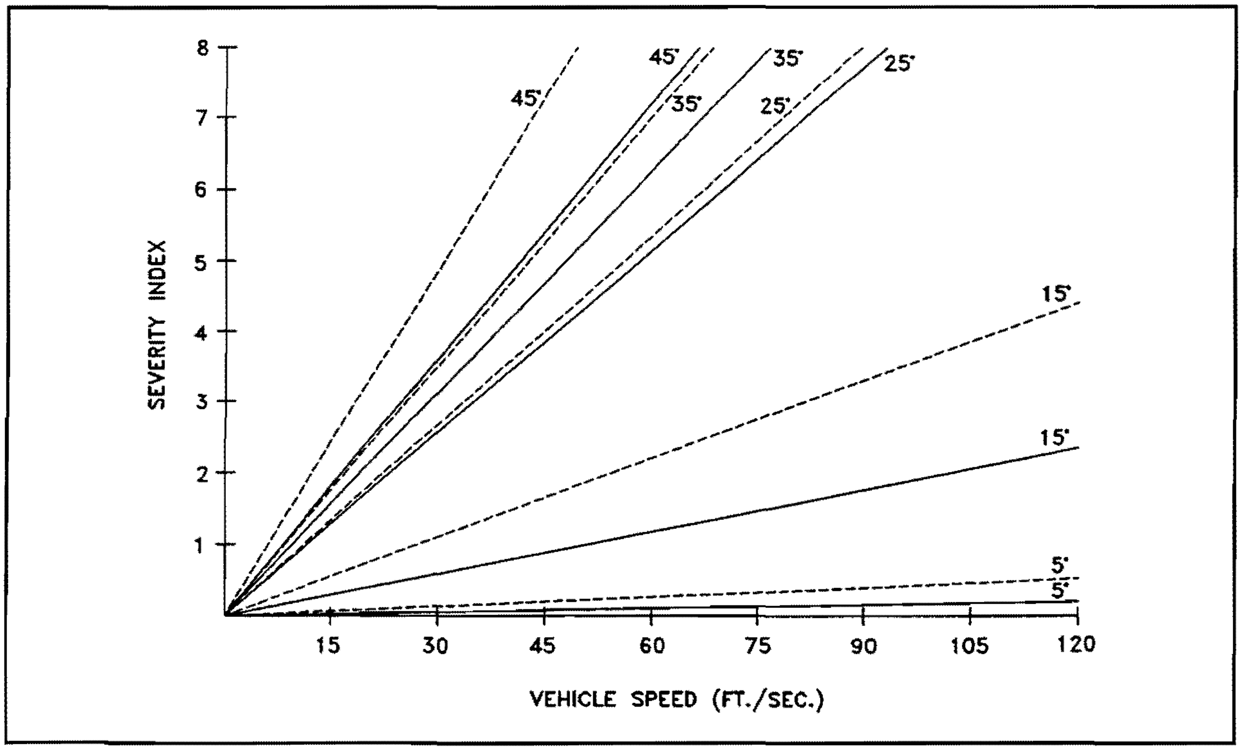


FIGURE B-15. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #8 (12.5 ft Tubular Transition)

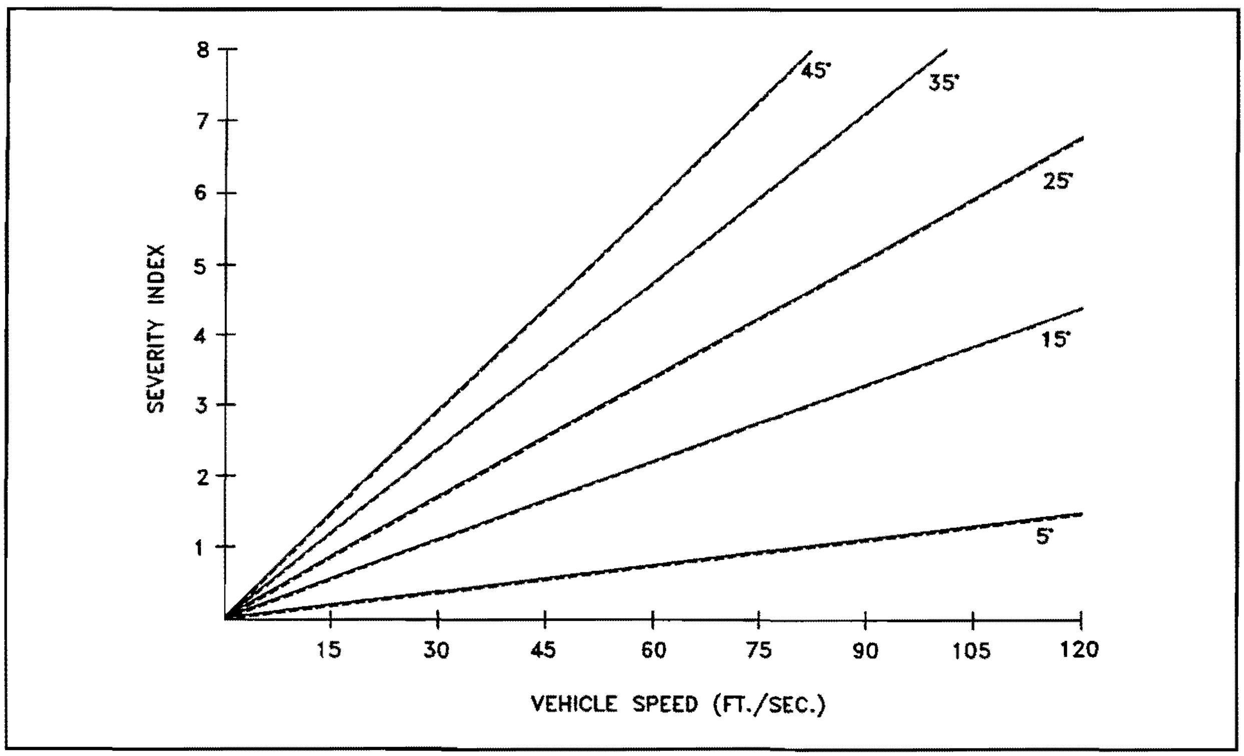


FIGURE B-16. Severity Curve for 60 mph Short Radius W-Beam System: Hazard #9 (Bridge Wall)

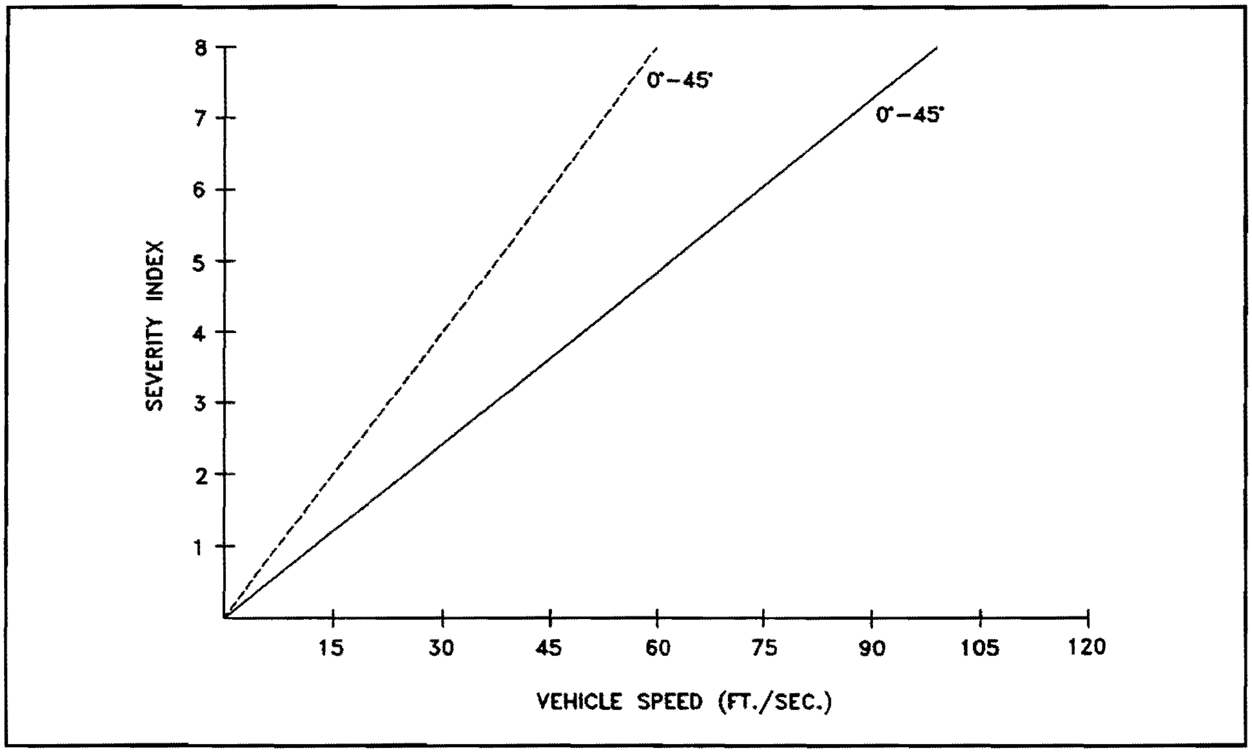


FIGURE B-17. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #1 (12.5 ft Turndown)

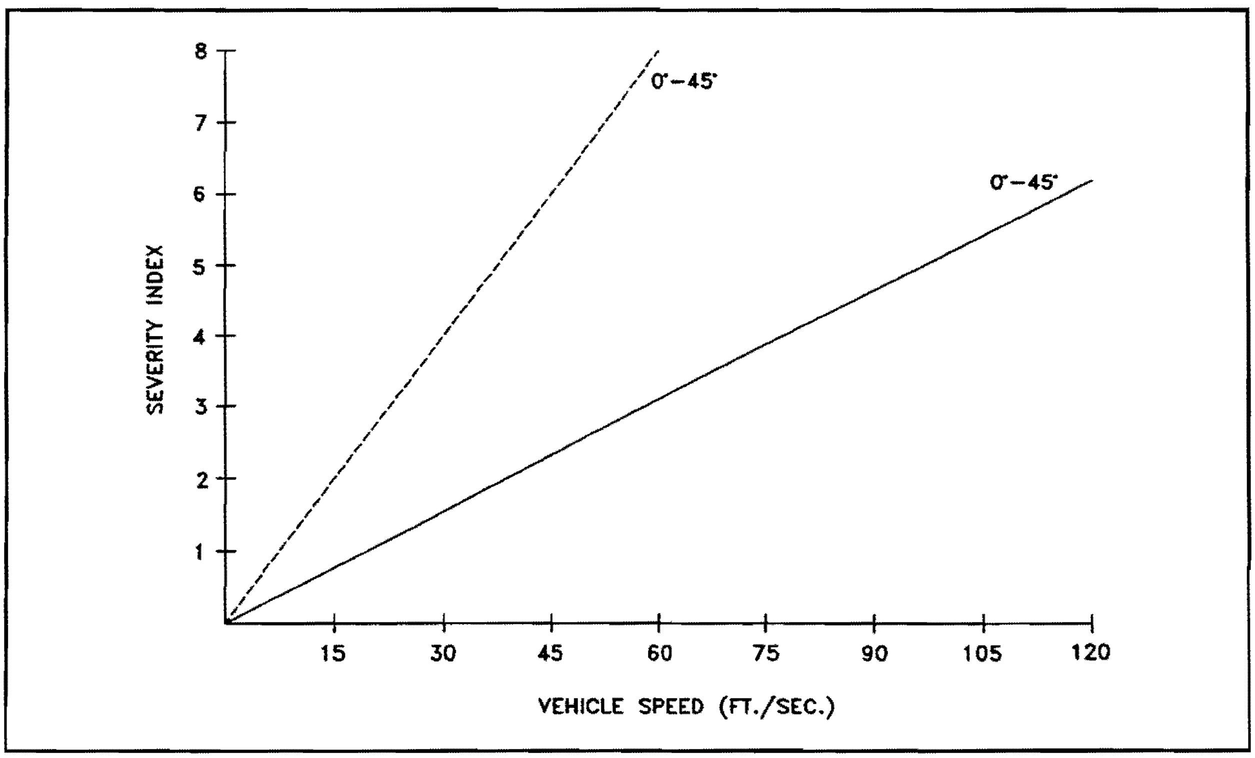


FIGURE B-18. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #2 (12.5 ft of Thrie Beam before Turndown)

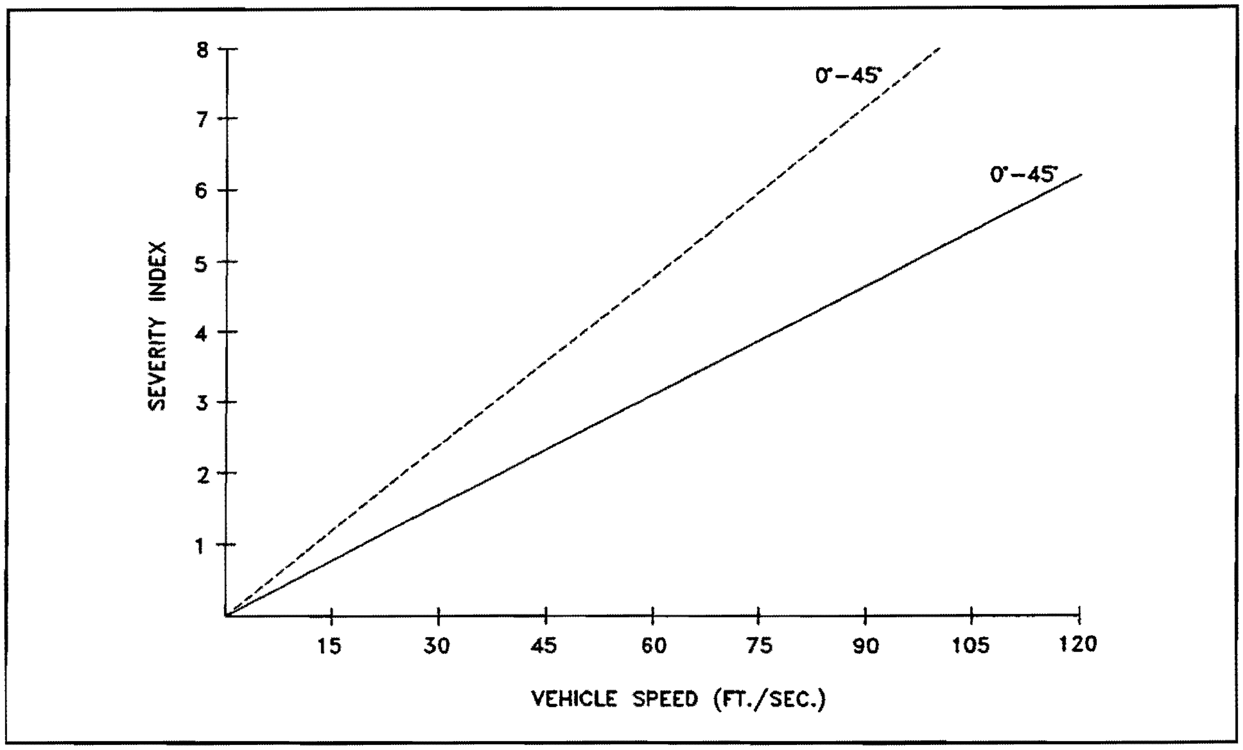


FIGURE B-19. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #3 (Straight Rail Prior to Curve)

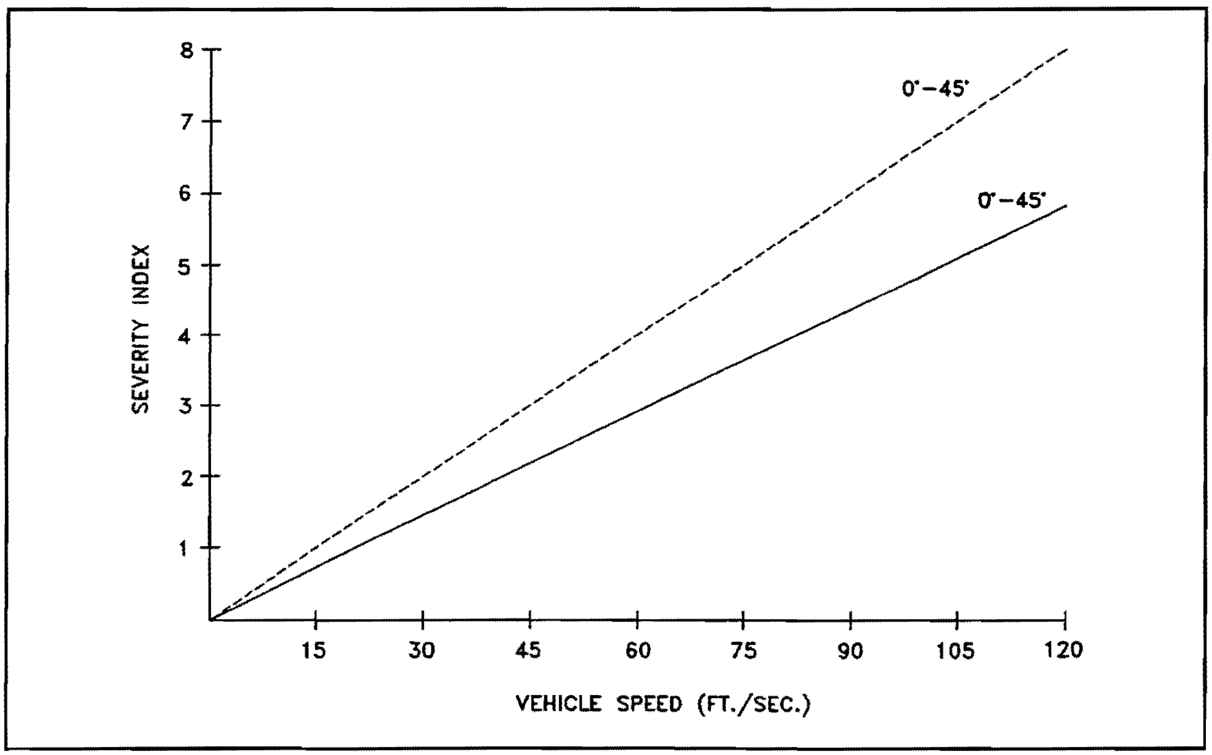


FIGURE B-20. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #4 (Rail Between Upstream Posts in Curve)

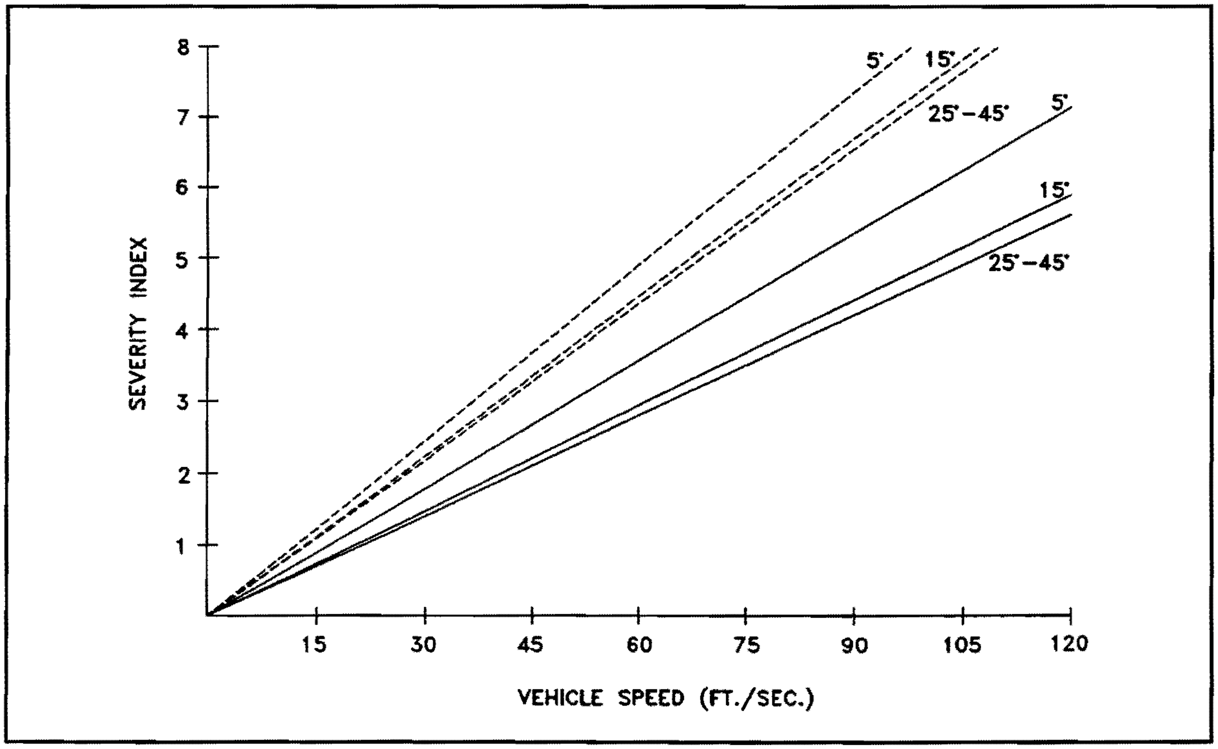


FIGURE B-21. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #5 (Rail Between Second Pair of Posts in Curve)

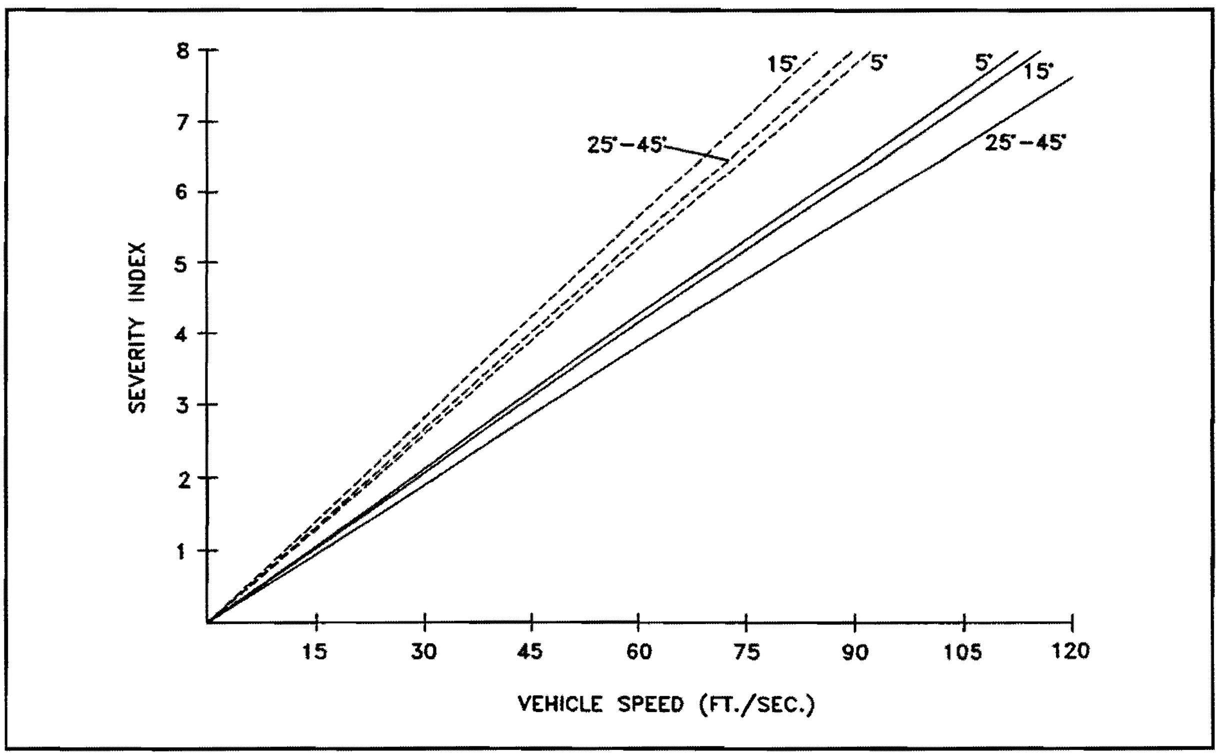


FIGURE B-22. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #6 (Rail Between Third Pair of Posts in Curve)

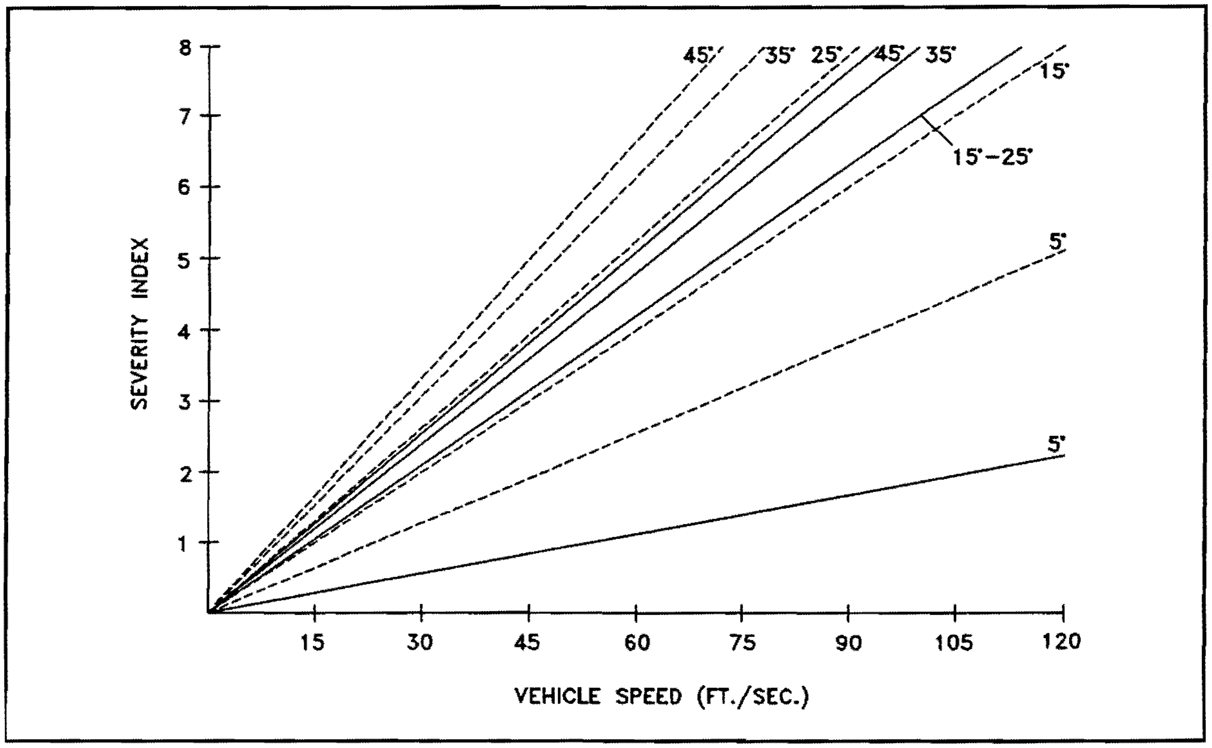


FIGURE B-23. Severity Curve for 60 wpm Short Radius Thrie Beam System: Hazard #7 (Rail Between Last Pair of Posts in Curve)

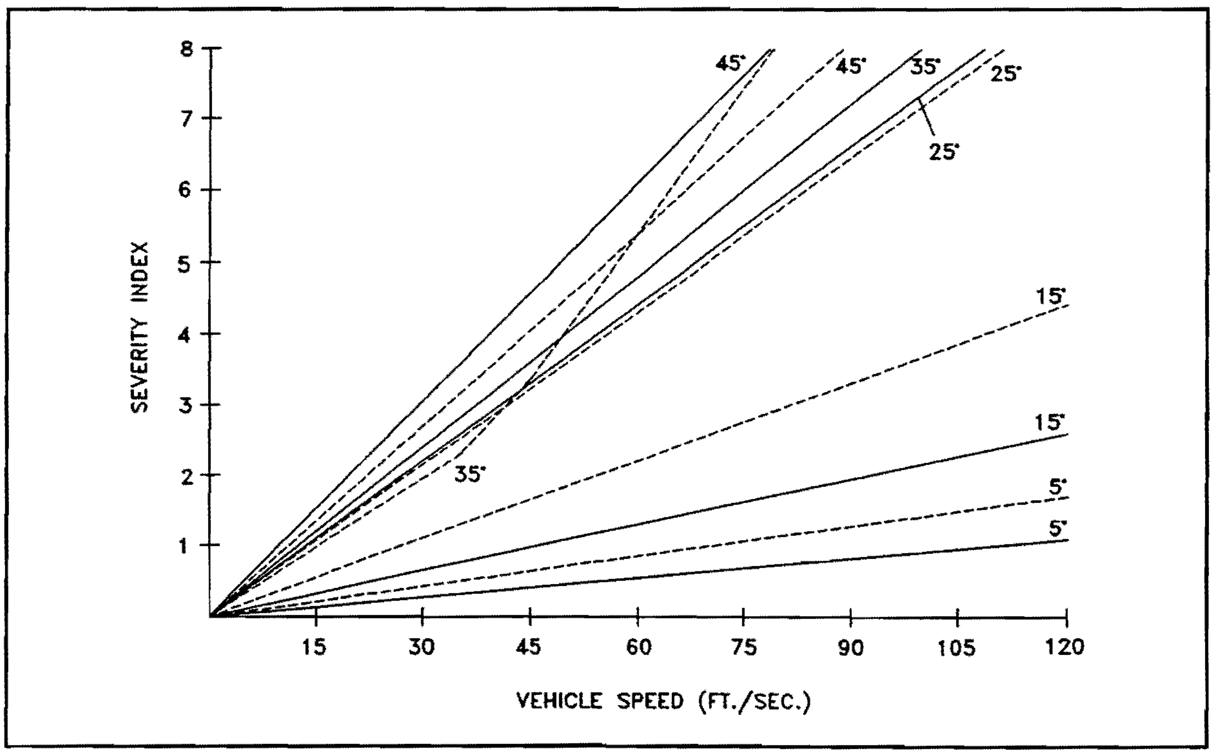


FIGURE B-24. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #8 (Rail Between Curve and Nested Transition)

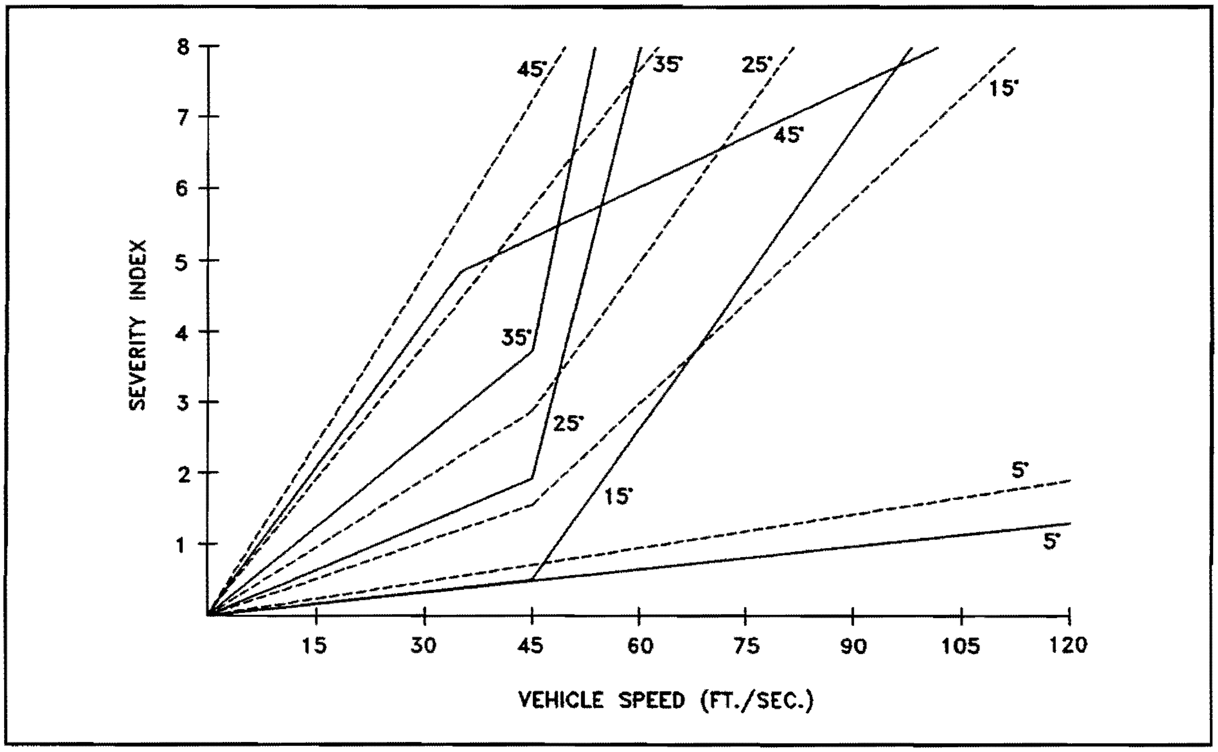


FIGURE B-25. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #9 (7.8 ft Transition)

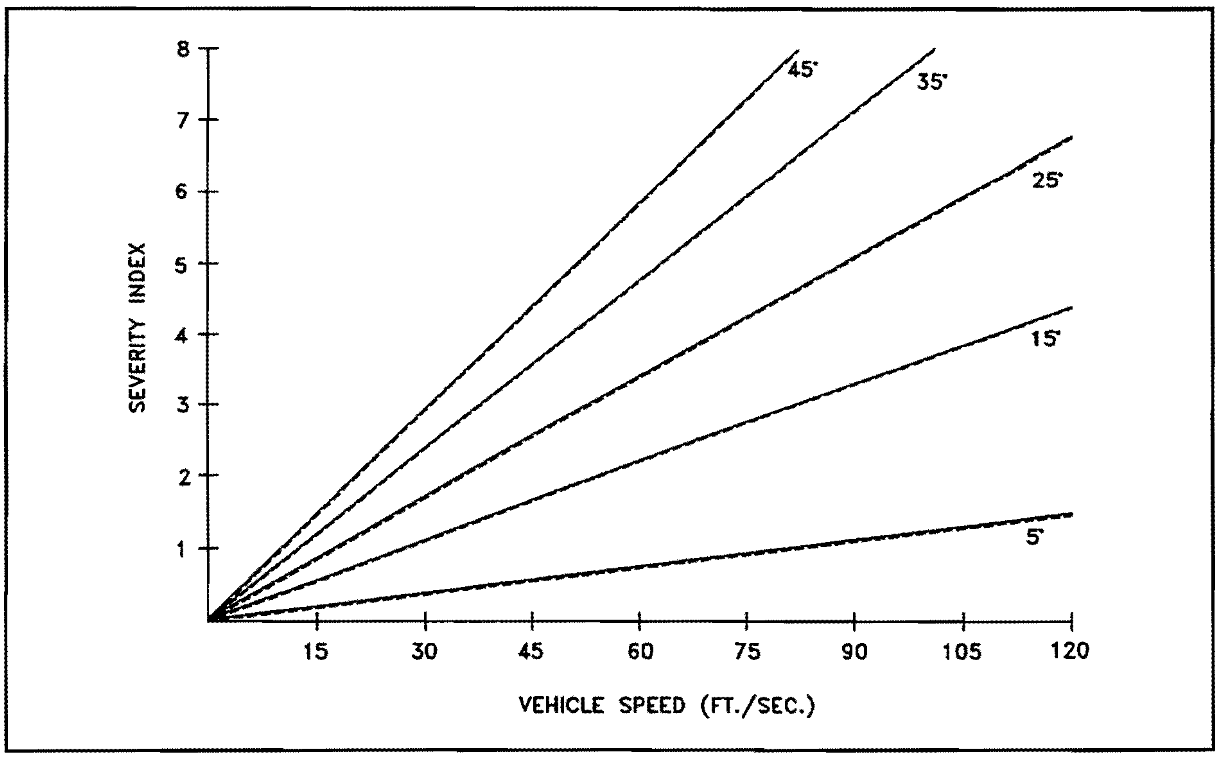


FIGURE B-26. Severity Curve for 60 mph Short Radius Thrie Beam System: Hazard #10 (Bridge Wall)

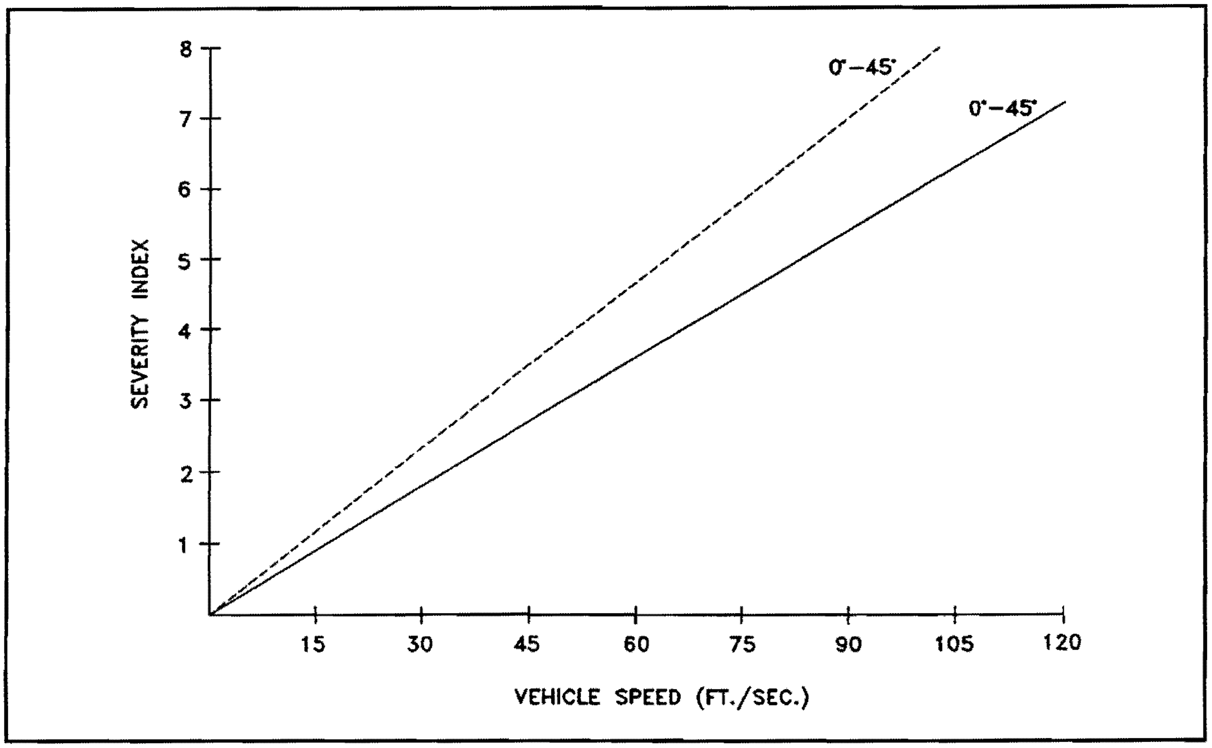


FIGURE B-27. Severity Curve for TREND: Hazard #1 (End of TREND)

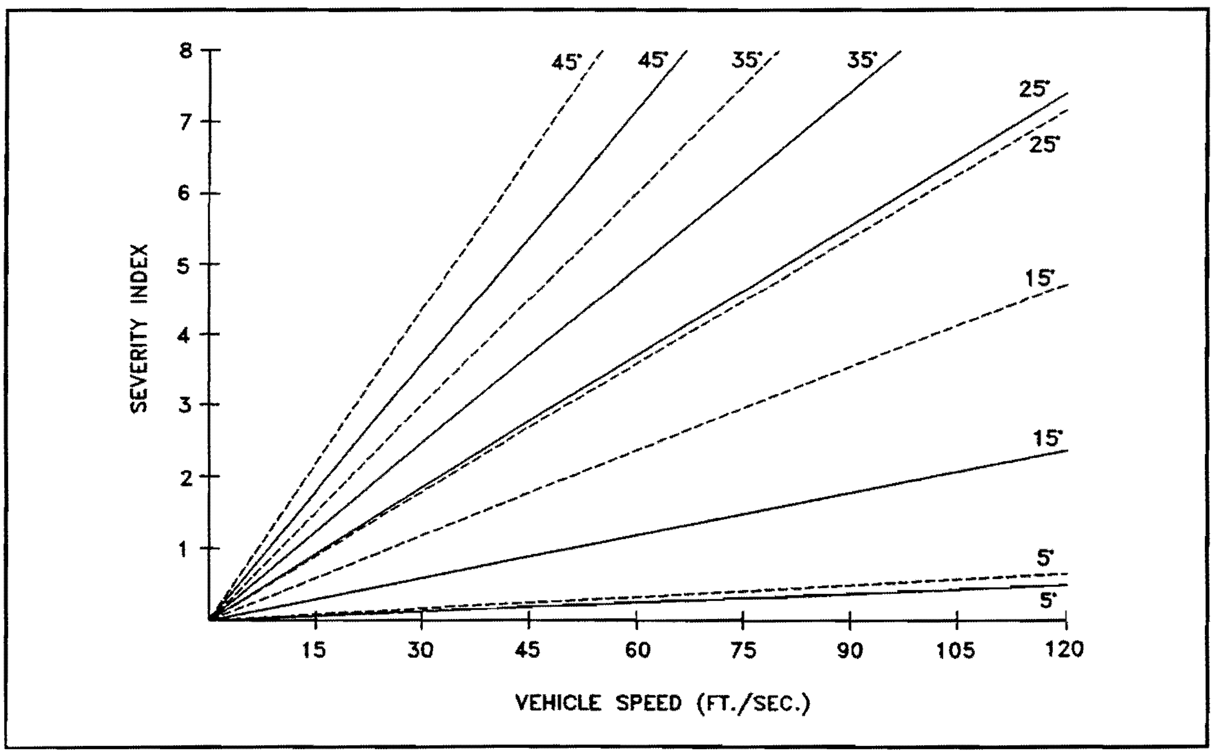


FIGURE B-28. Severity Curve for TREND: Hazard #2 (18 ft of TREND Along Primary Road)

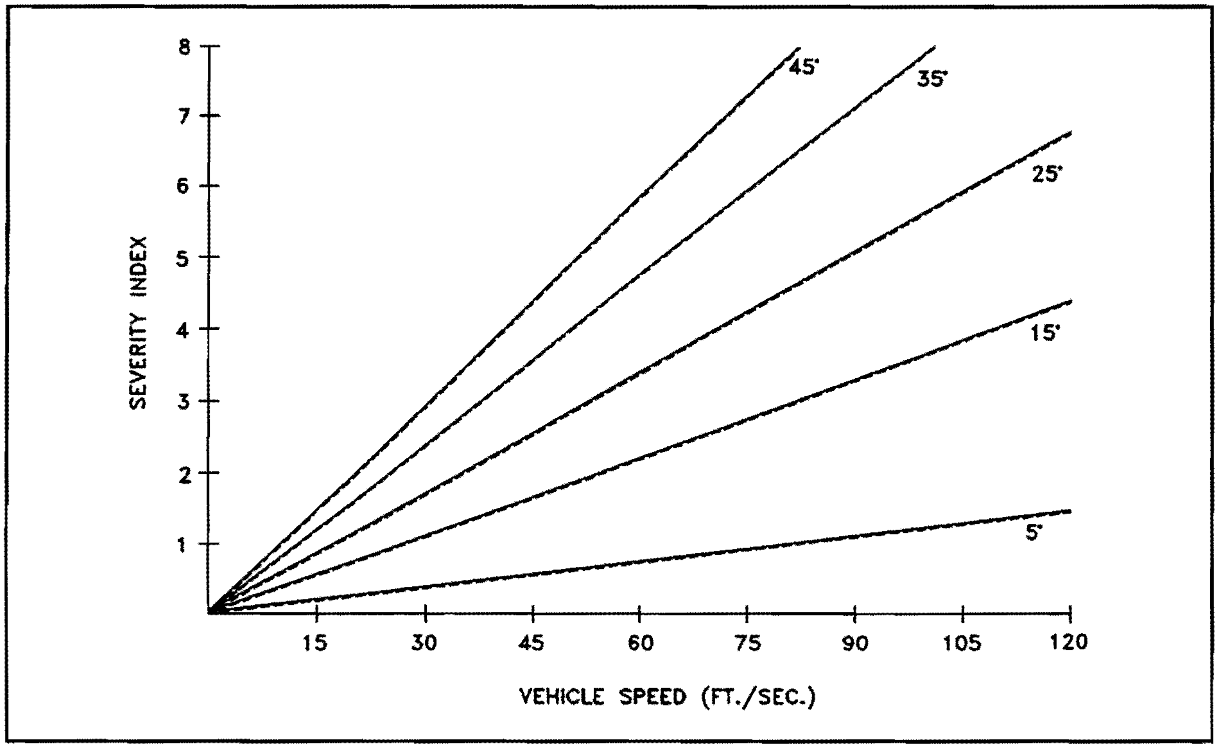


FIGURE B-29. Severity Curve for TREND: Hazard #3 (Bridge Wall)

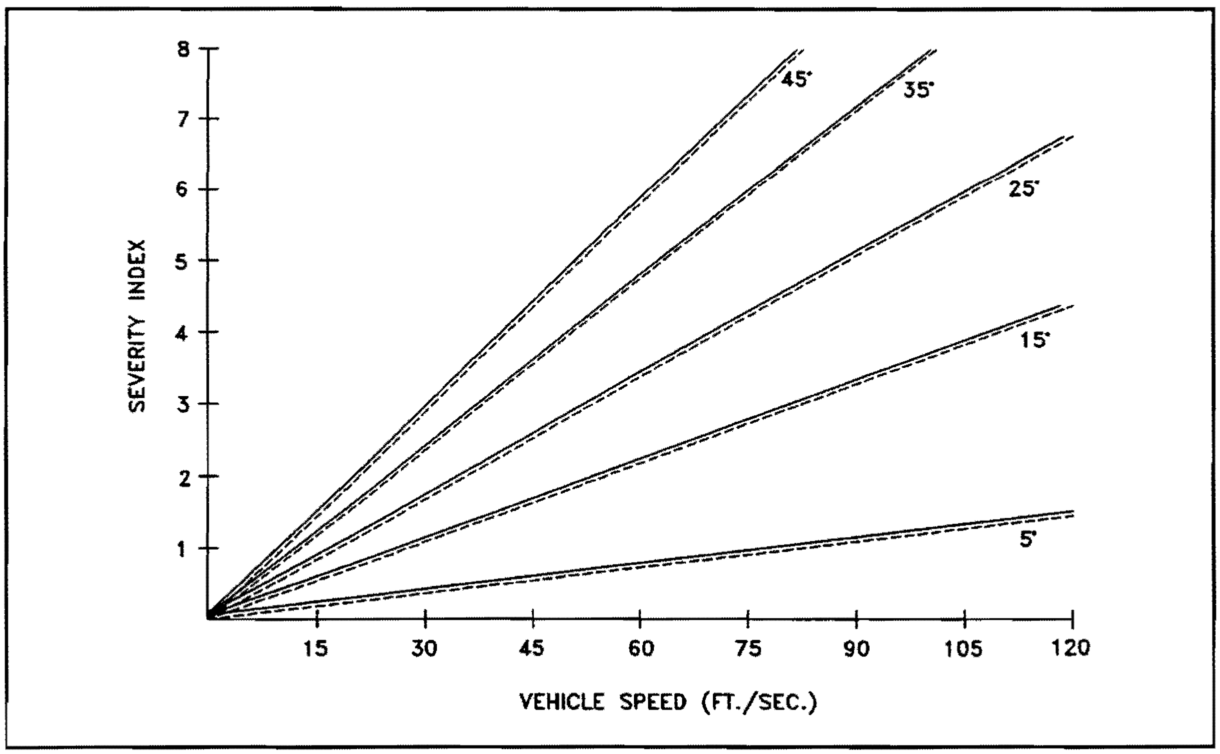


FIGURE B-30. Severity Curve for Sand Tubs: Hazard #1 (Leading Tub)

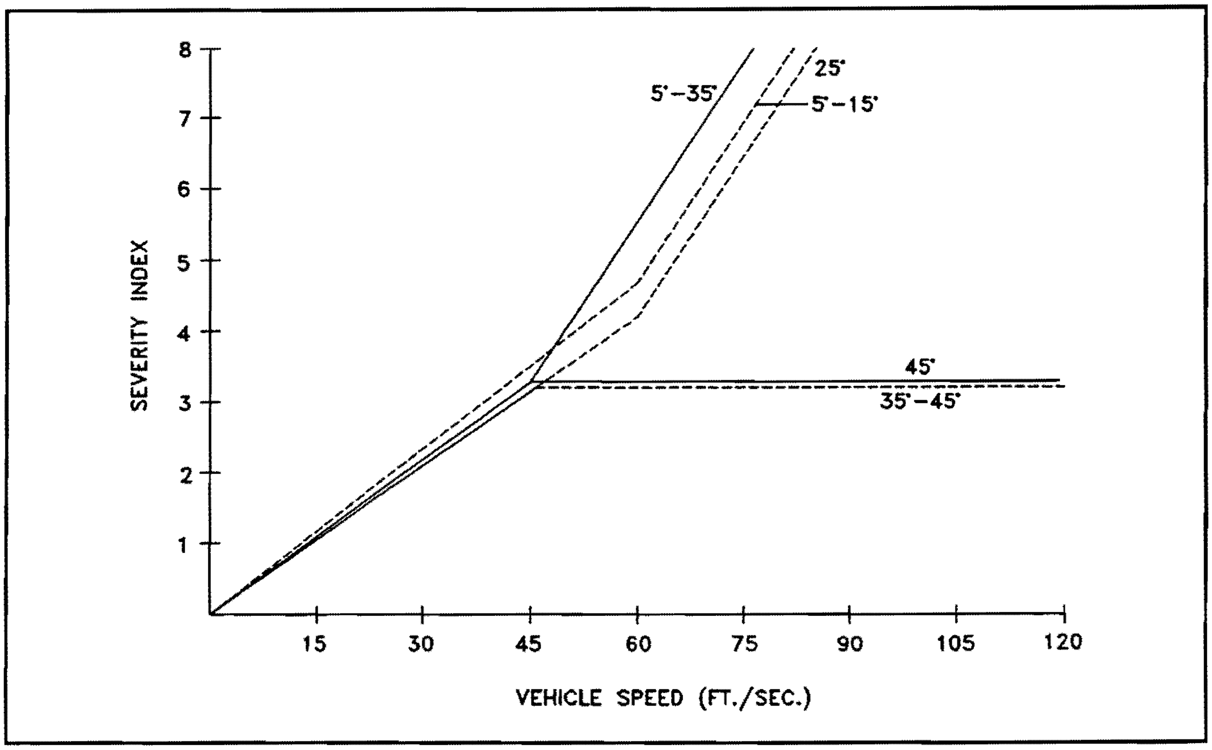


FIGURE B-31. Severity Curve for Sand Tubs: Hazard #2 (Second Tub and Third Set of Tubs)

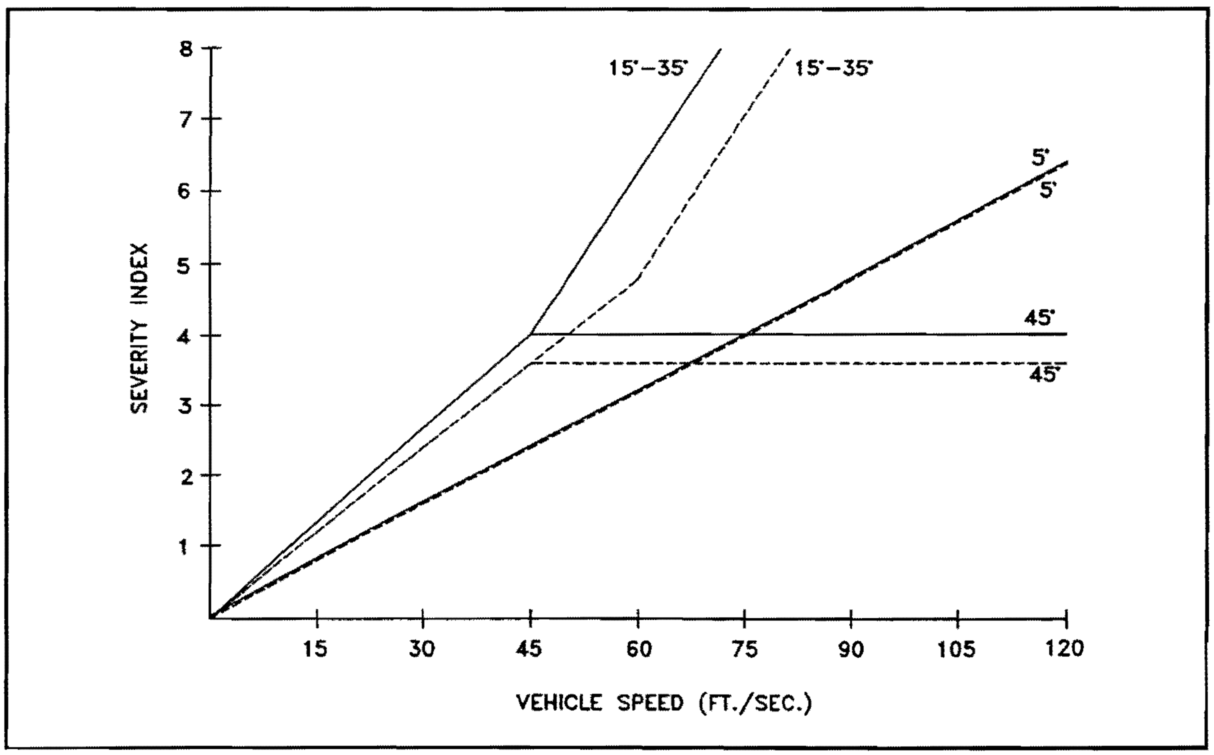


FIGURE B-32. Severity Curve for Sand Tubs: Hazard #3 (4th and 5th Set of Tubs)

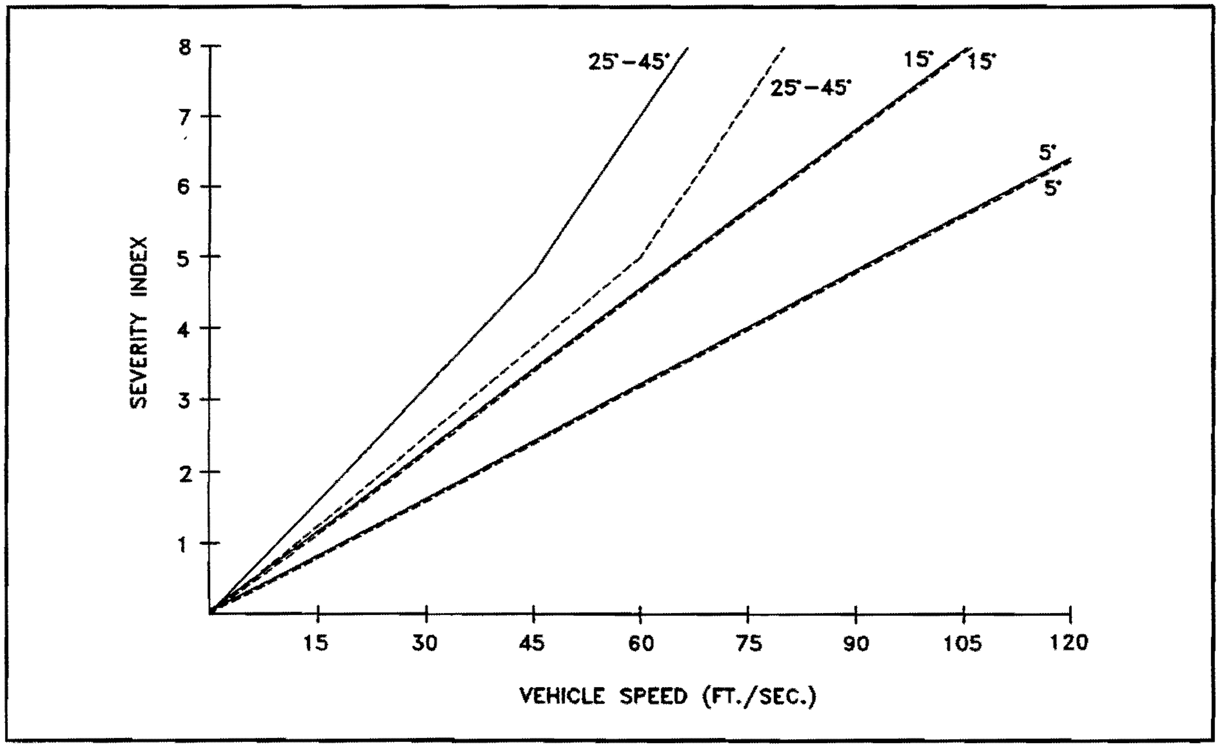


FIGURE B-33. Severity Curve for Sand Tubs: Hazard #4 (6th Set of Tubs)

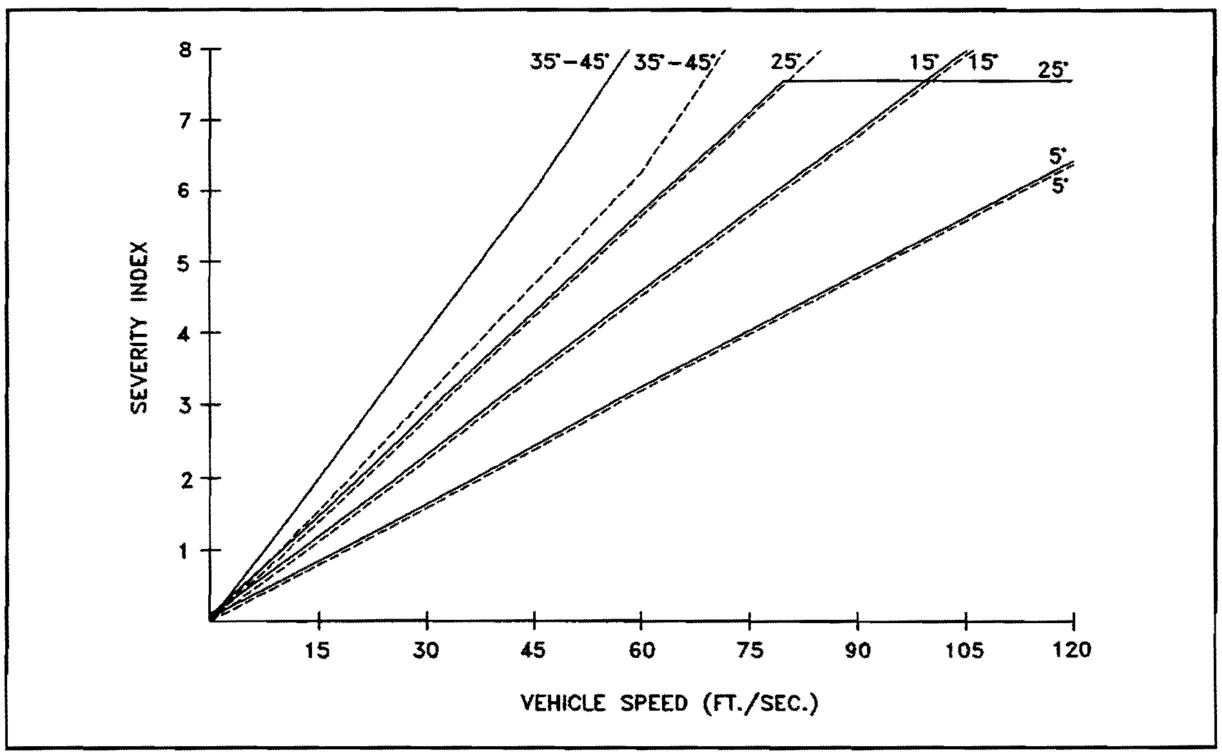


FIGURE B-34. Severity Curve for Sand Tubs: Hazard #5 (7th Set of Tubs)

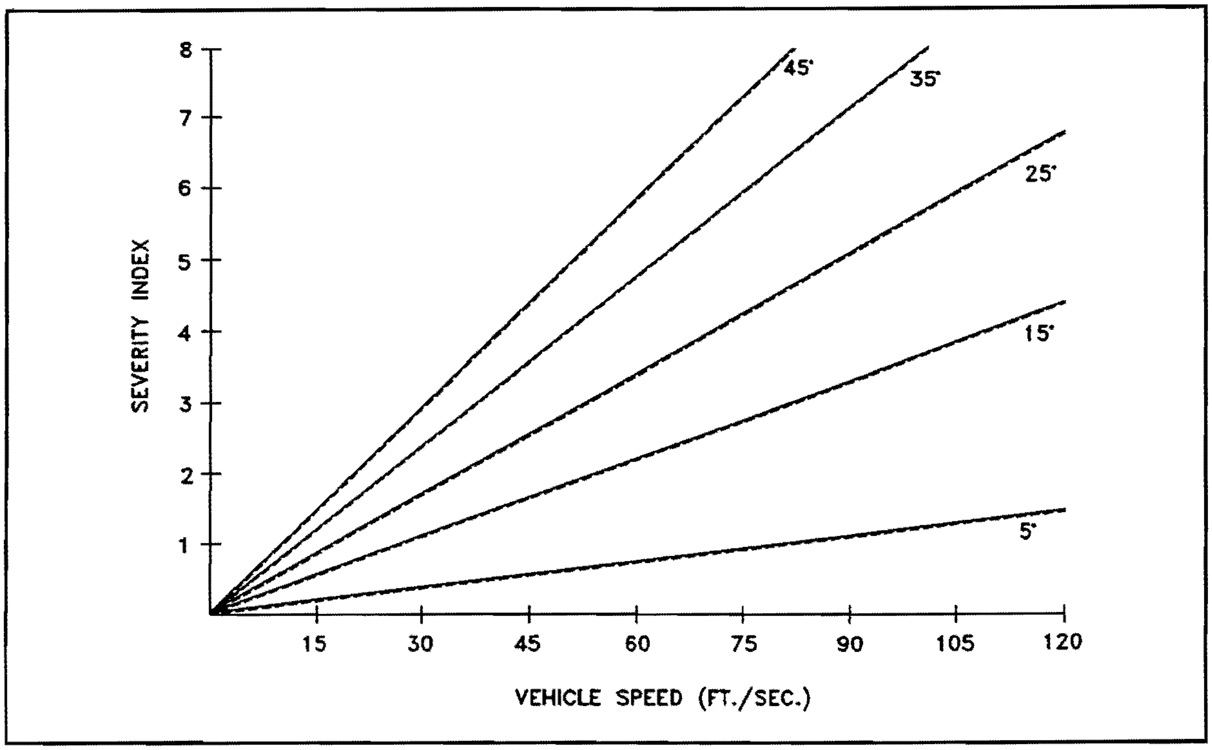


FIGURE B-35. Severity Curve for Sand Tubs: Hazard #6 (Bridge Wall)

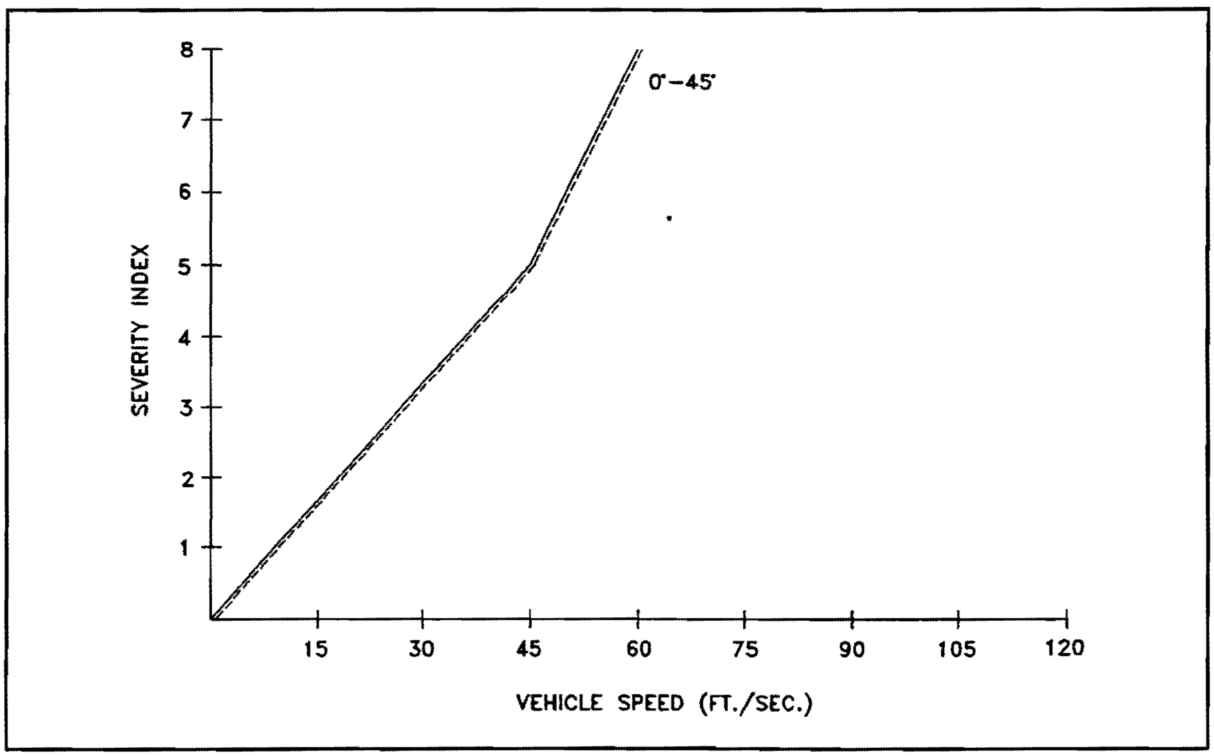


FIGURE B-36. Severity Curve for W-Beam Rail with Turndown: Hazard #1 (End of Turndown)

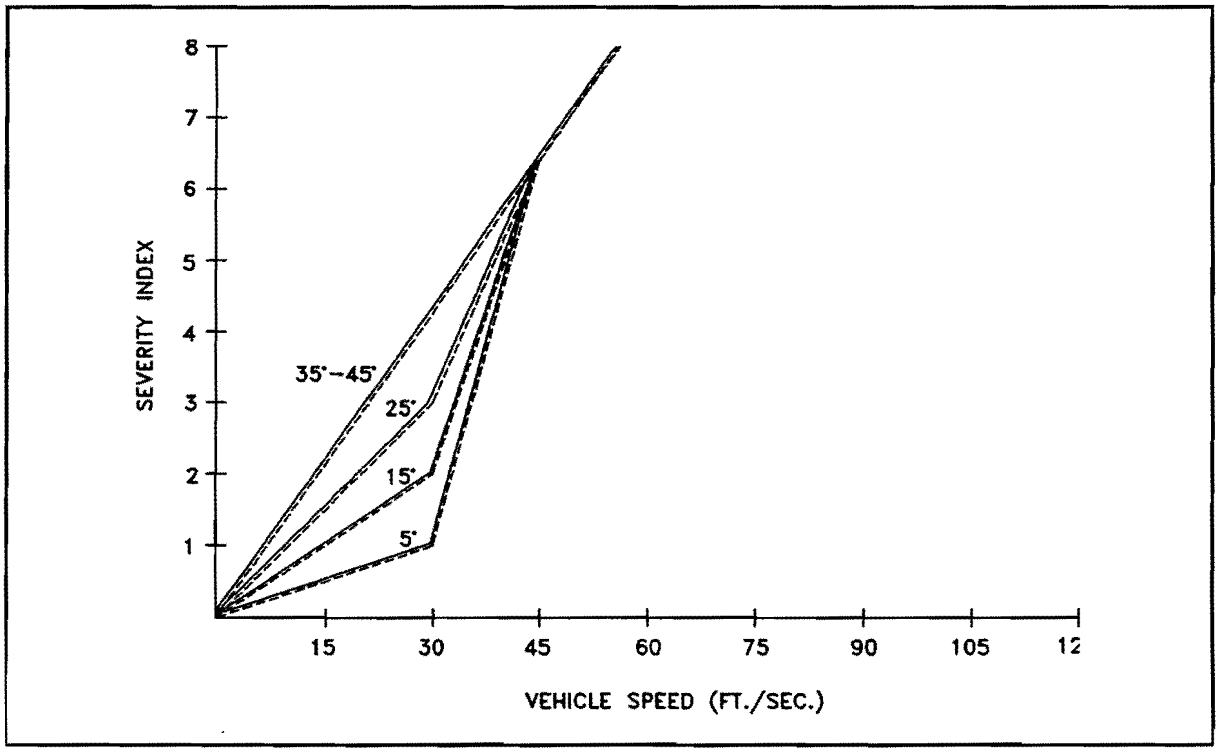


FIGURE B-37. Severity Curve for W-Beam Rail with Turndown: Hazard #2 (First 9 ft of Turndown)

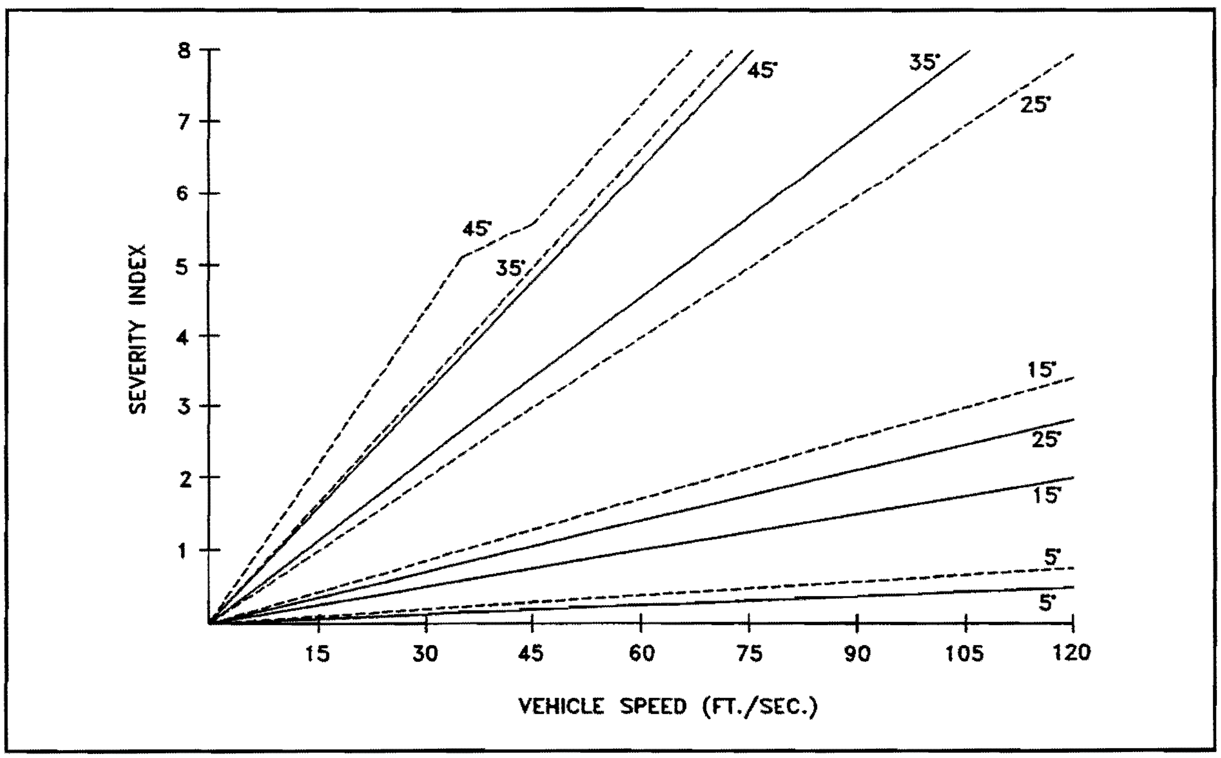


FIGURE B-38. Severity Curve for W-Beam Rail with Turndown: Hazard #3 (Last 3 ft of Turndown + 37.5 ft of W-Beam)

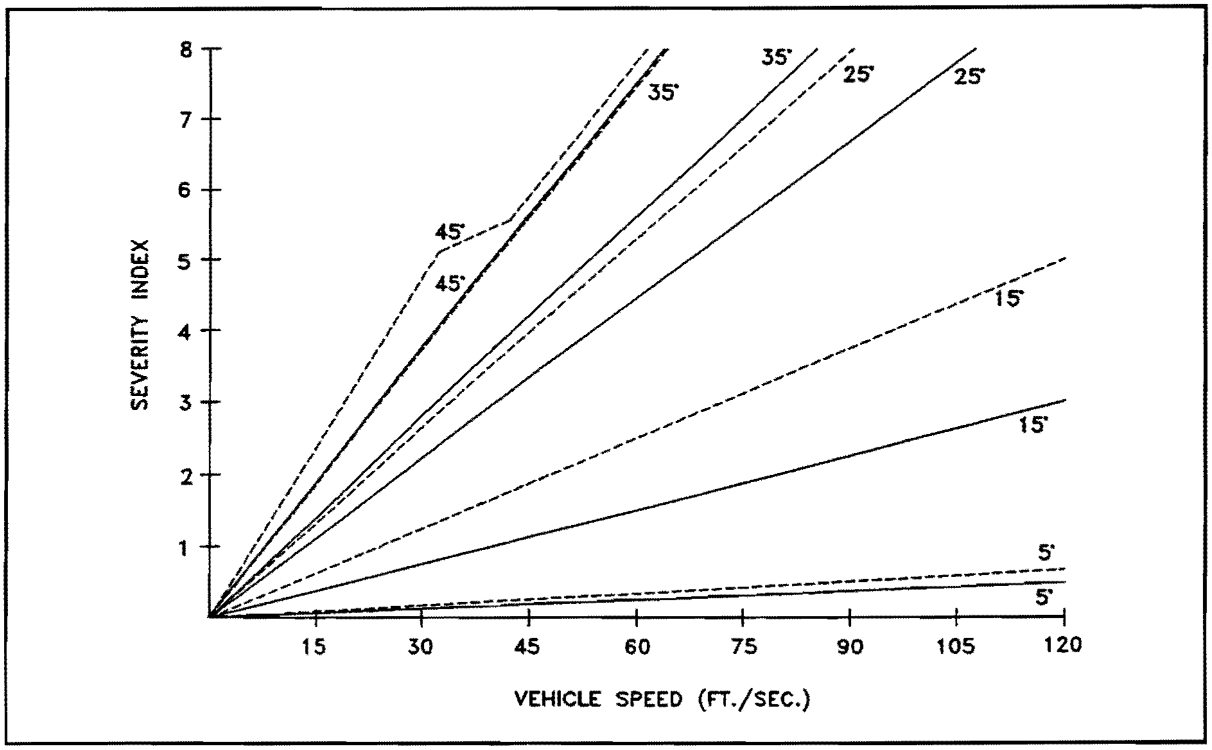


FIGURE B-39. Severity Curve for W-Beam Rail with Turndown: Hazard #4 (Last 12.5 ft of W-Beam Prior to Transition)

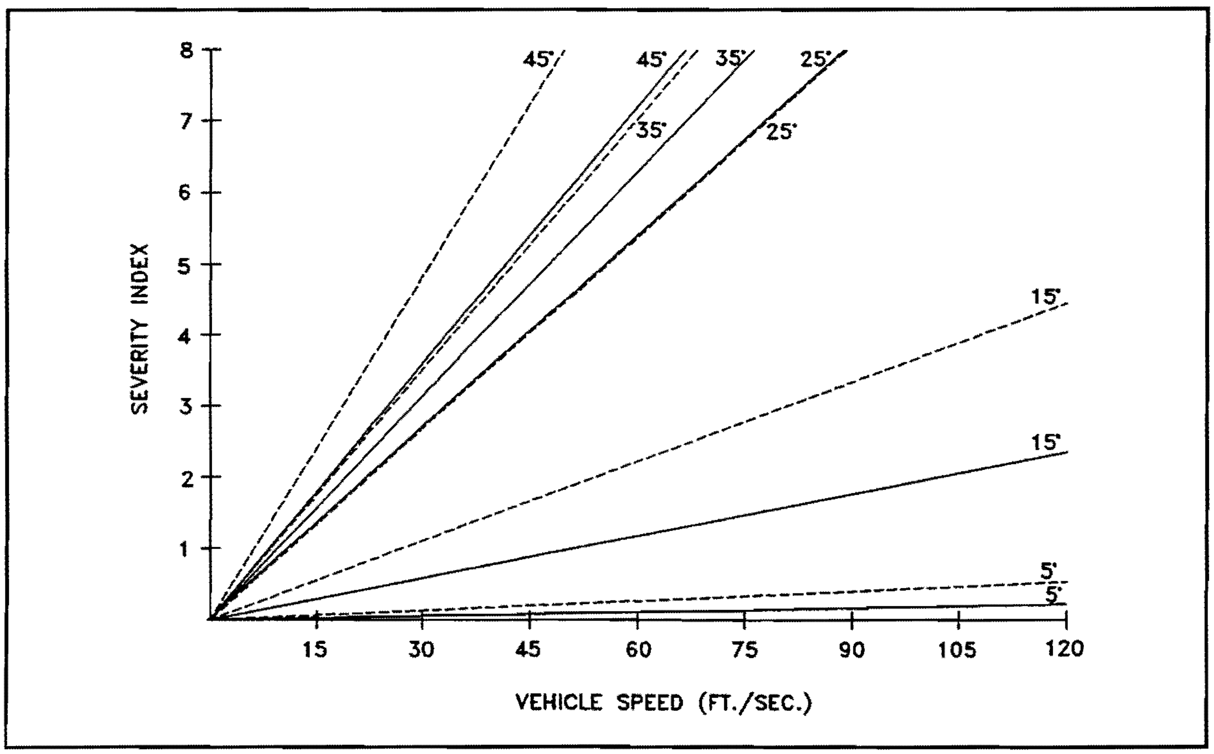


FIGURE B-40. Severity Curve for W-Beam Rail with Turndown: Hazard #5 (12.5 ft Tubular Transition)

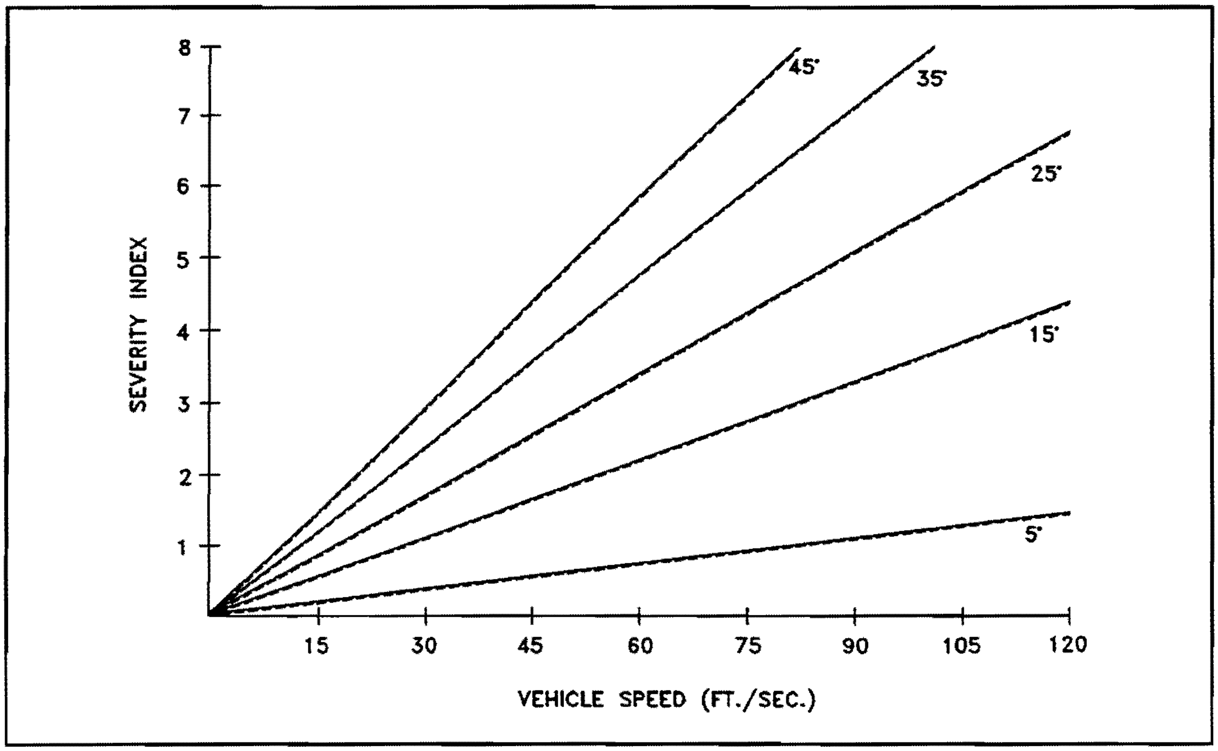


FIGURE B-41. Severity Curve for W-Beam Rail with Turndown: Hazard #6 (Bridge Wall)

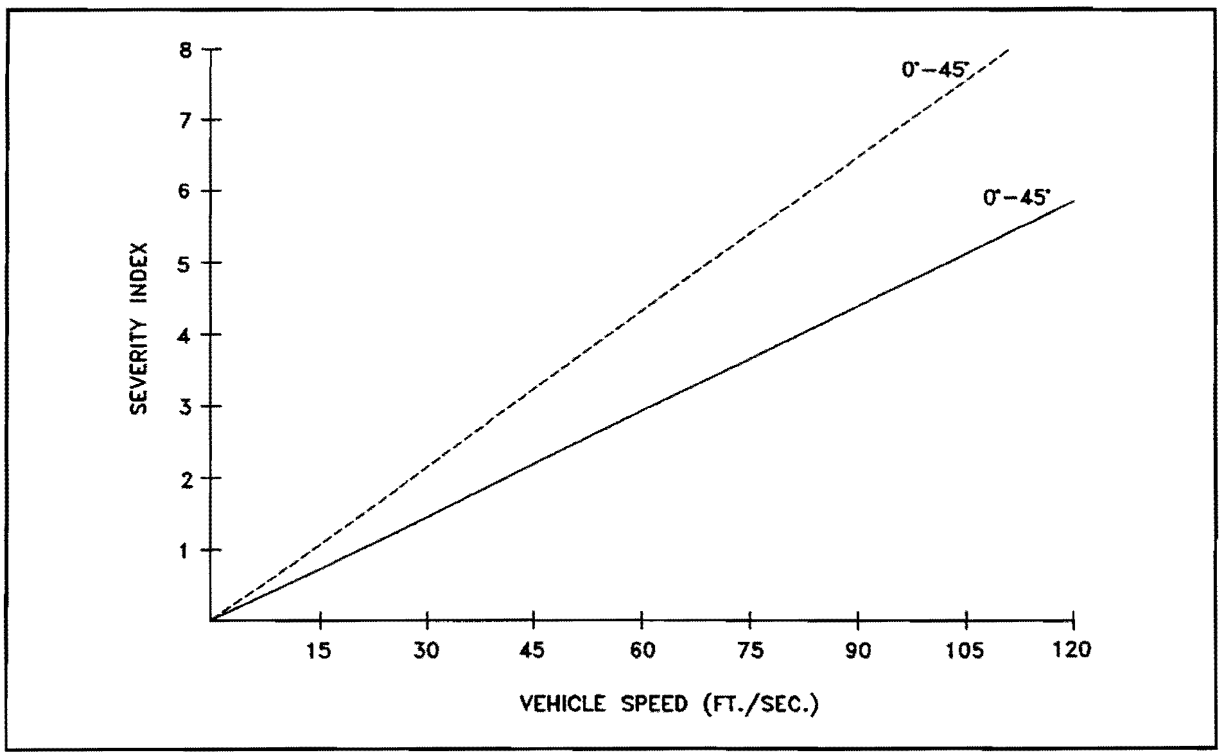


FIGURE B-42. Severity Curve for W-Beam Rail with ET-2000: Hazard #1 (End of Extruder)

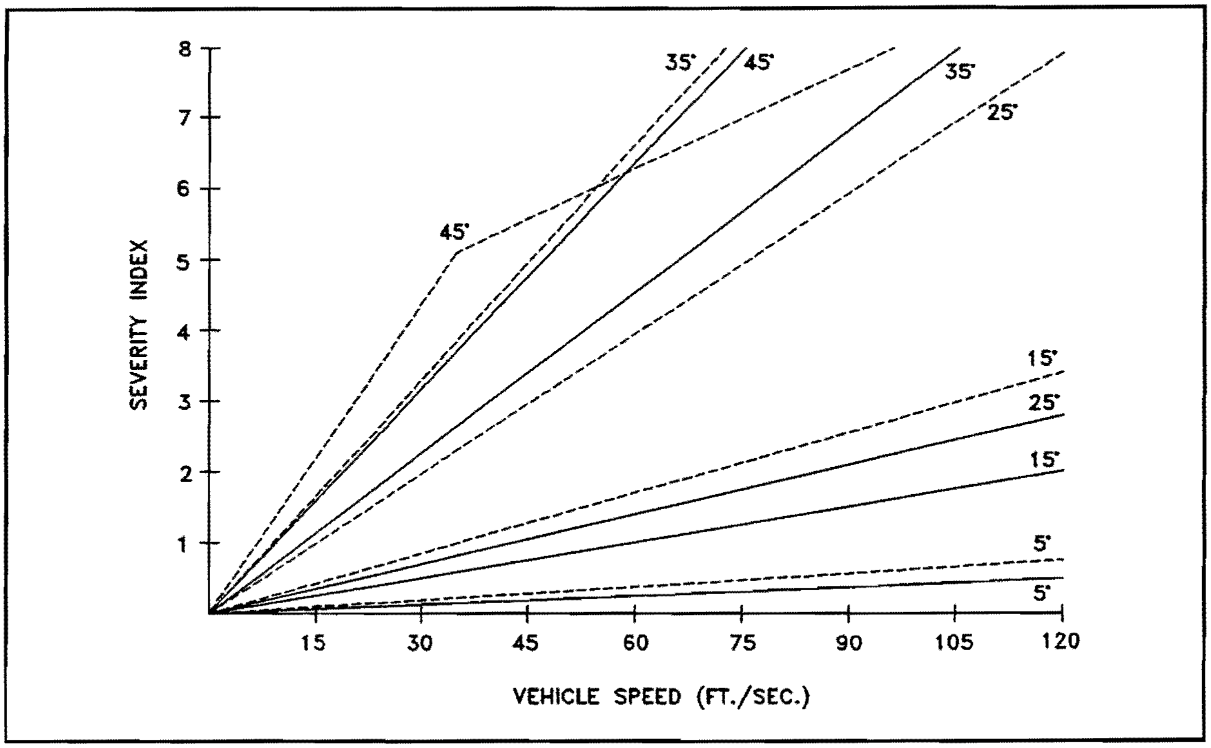


FIGURE B-43. Severity Curve for W-Beam Rail with ET-2000: Hazard #2 (37.5 ft of W-Beam after Extruder)

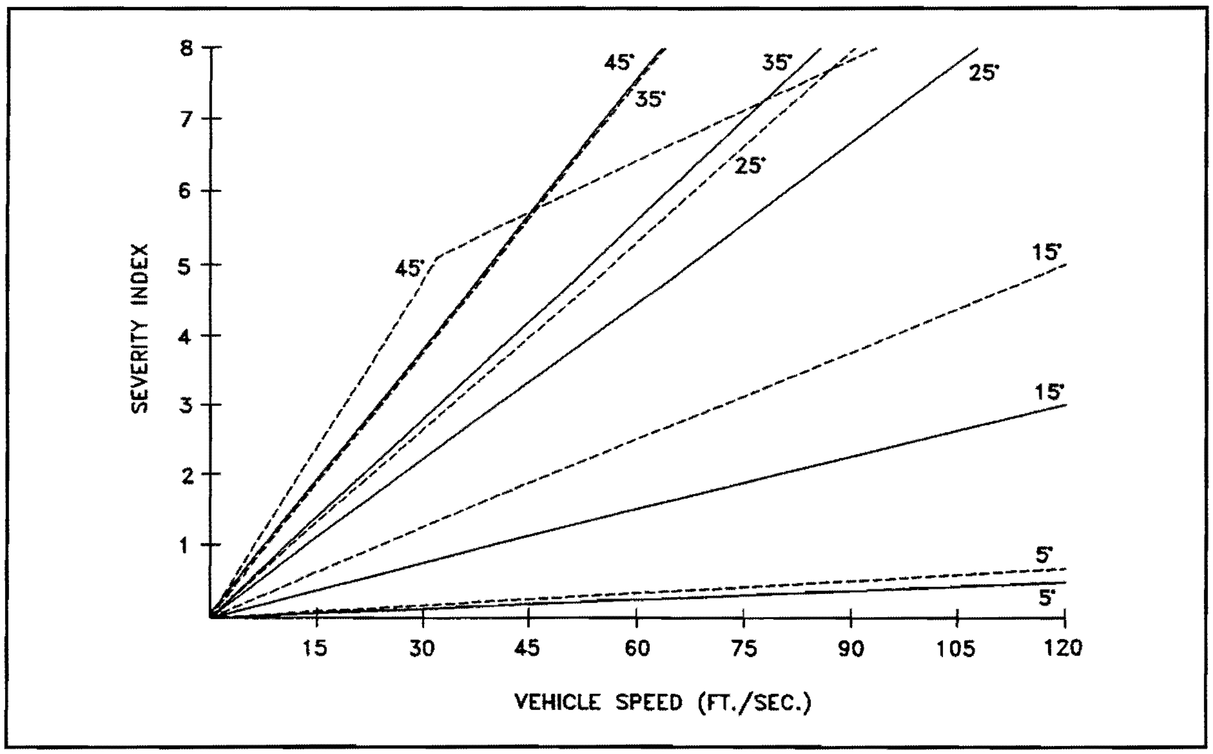


FIGURE B-44. Severity Curve for W-Beam Rail with ET-2000: Hazard #3 (Last 12.5 ft of W-Beam Prior to Transition)

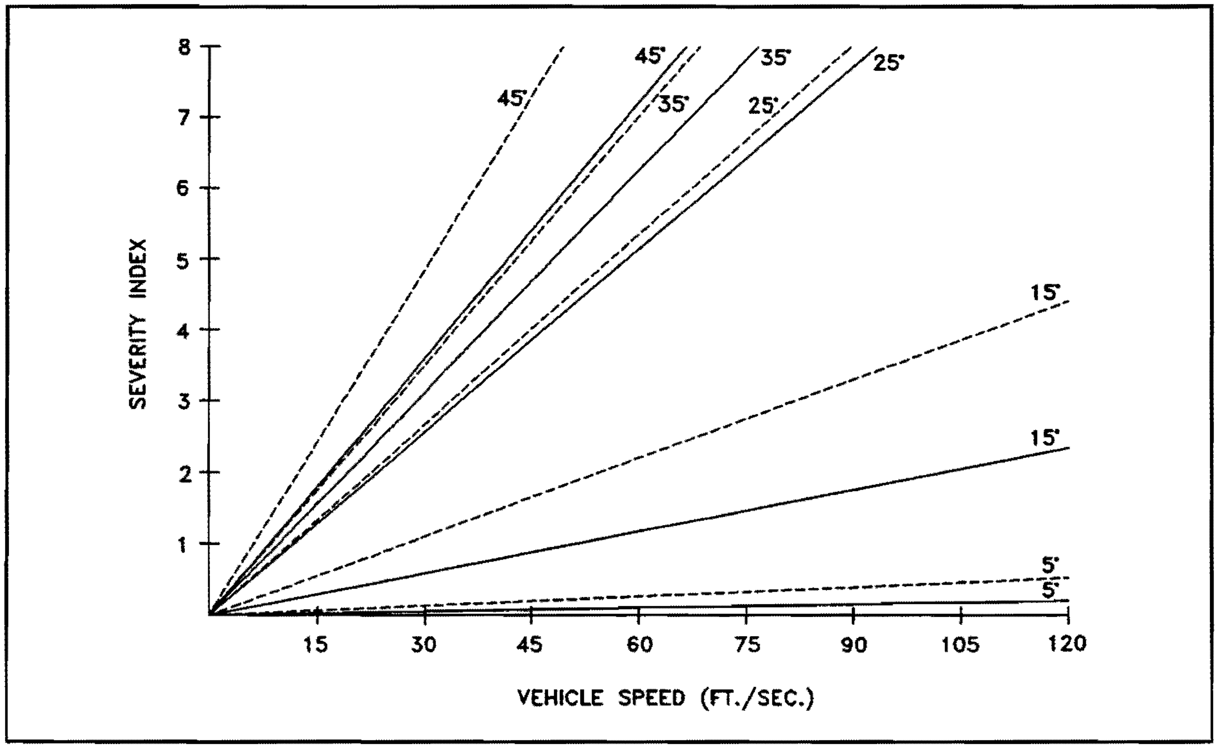


FIGURE B-45. Severity Curve for W-Beam Rail with ET-2000: Hazard #4 (12.5 ft Tubular Transition)

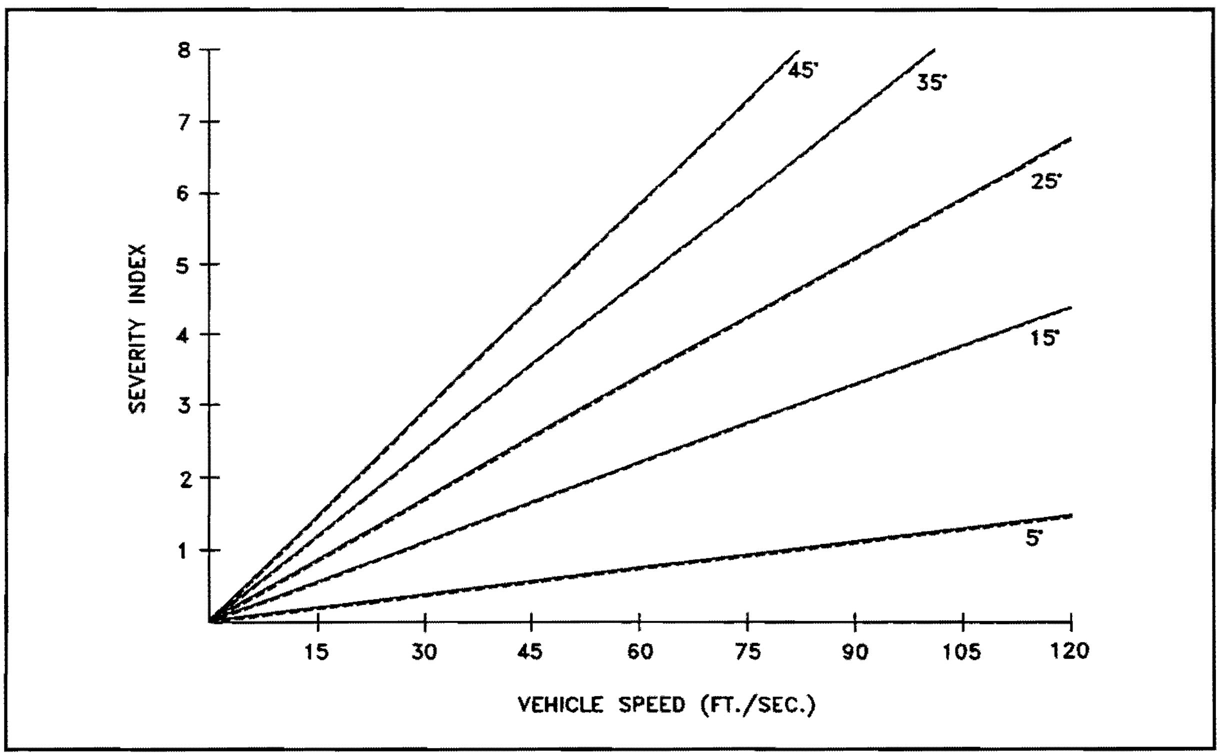


FIGURE B-46. Severity Curve for W-Beam Rail with ET-2000: Hazard #5 (Bridge Wall)

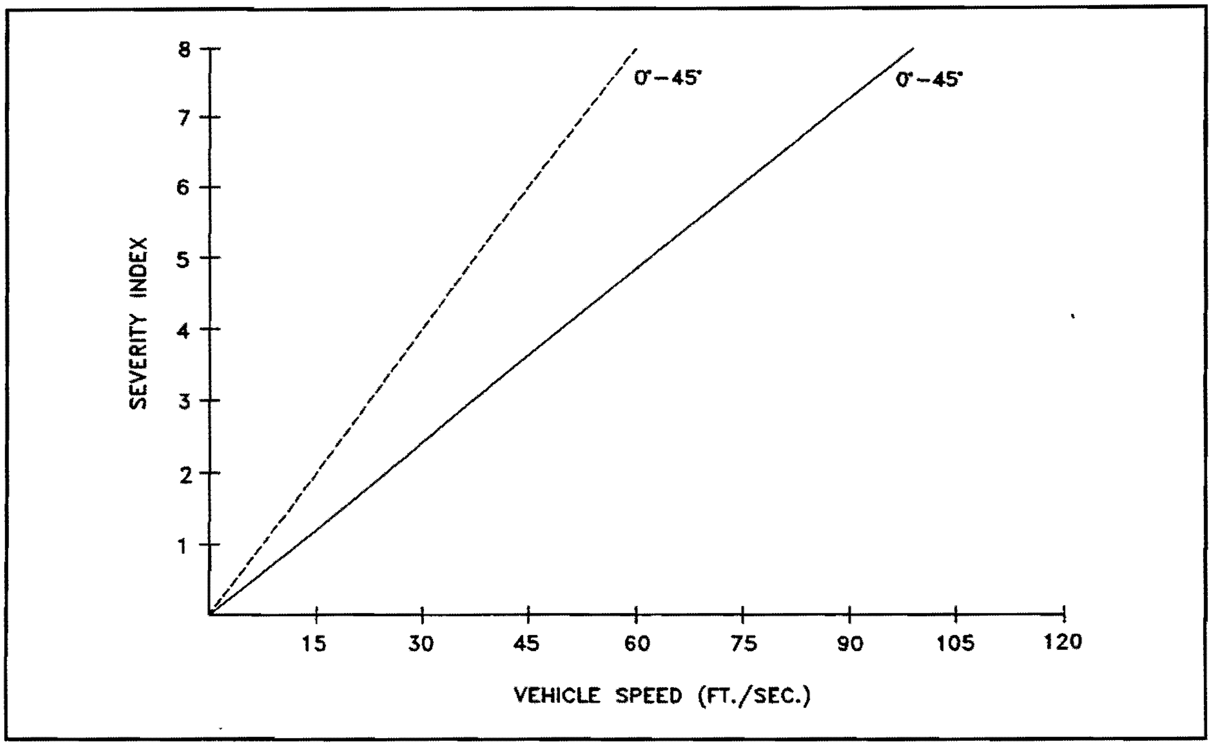


FIGURE B-47. Severity Curve for W-Beam with Curved End Treatment: Hazard #1 (12.5 ft Turndown)

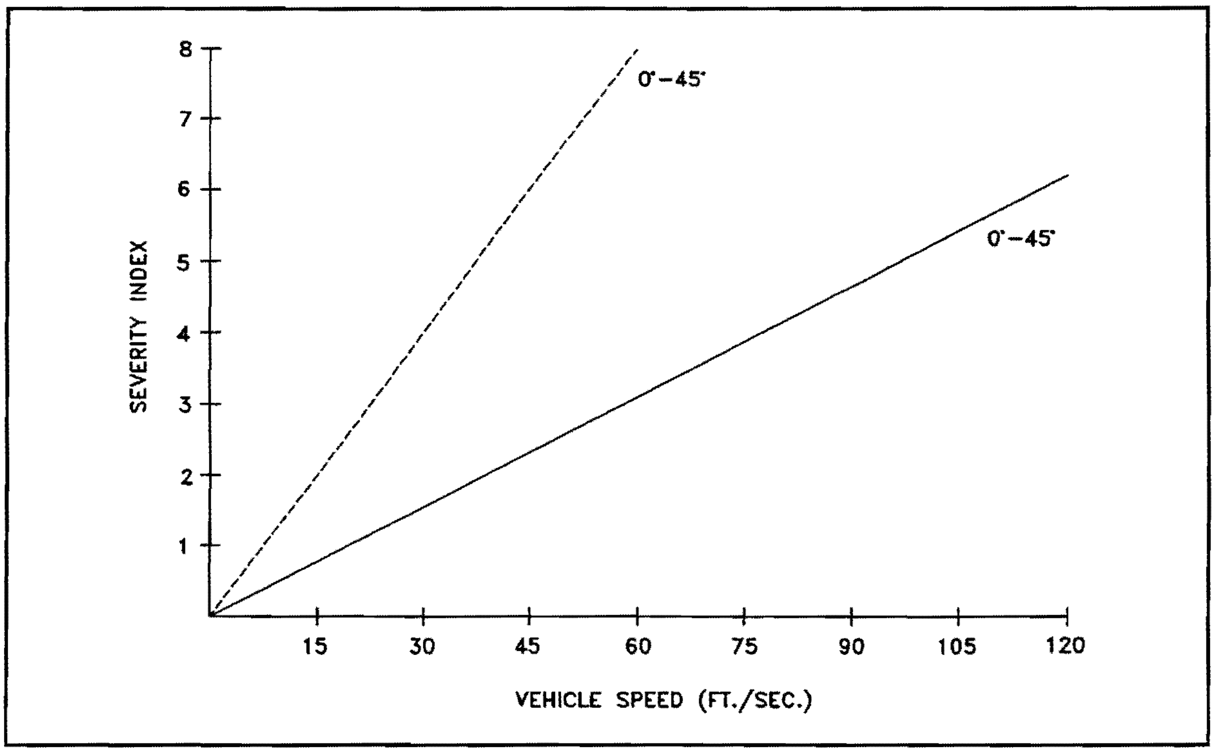


FIGURE B-48. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #2 (25 ft of Rail Between Turndown and Curve)

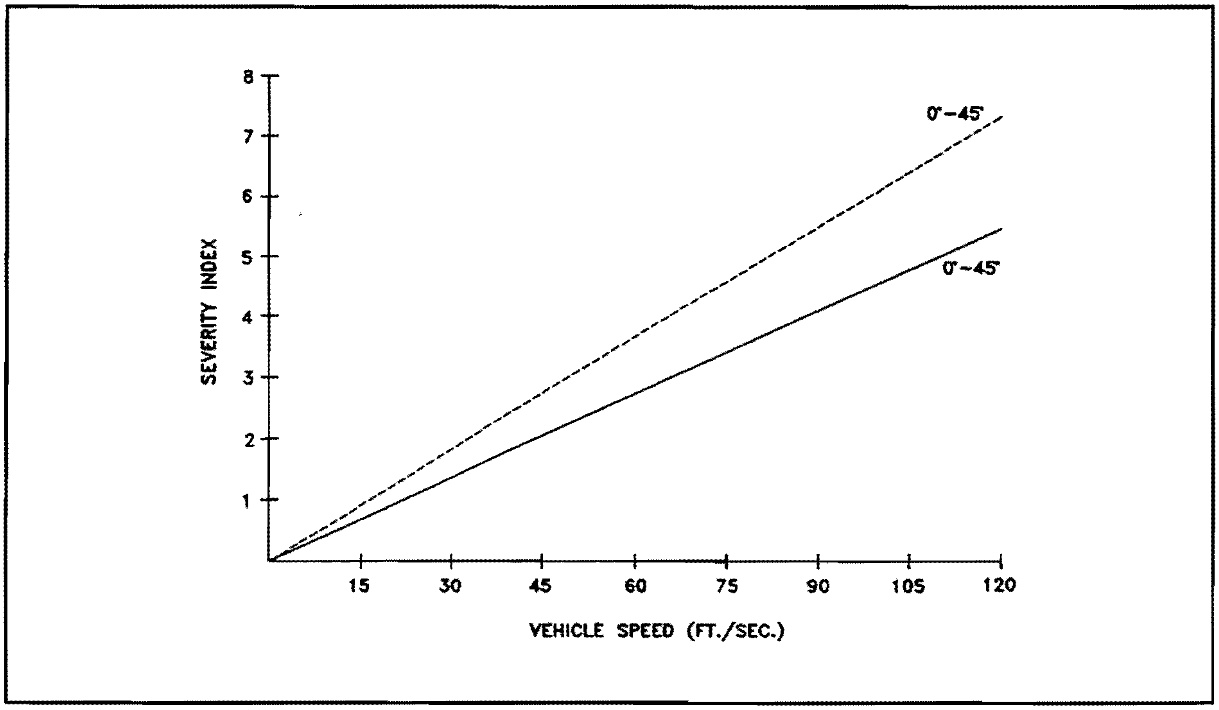


FIGURE B-49. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #3 (Rail Between Upstream Posts in Curve)

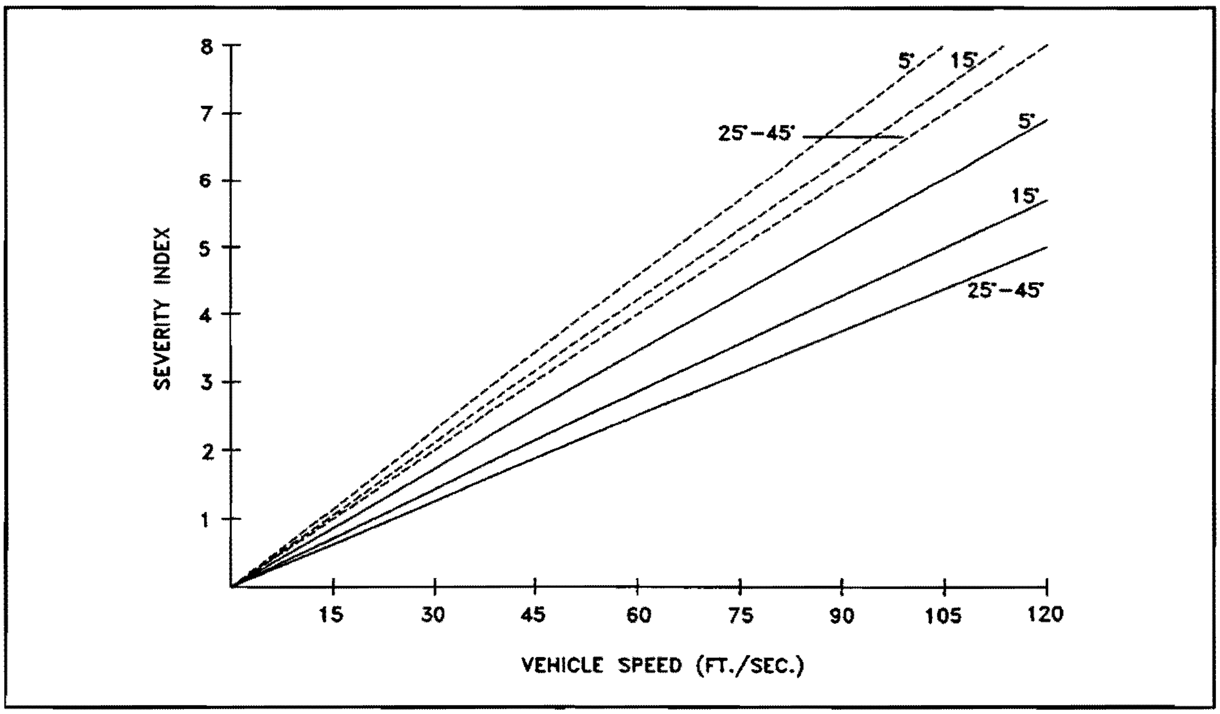


FIGURE B-50. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #4 (Rail Between Second Pair of Posts in Curve)

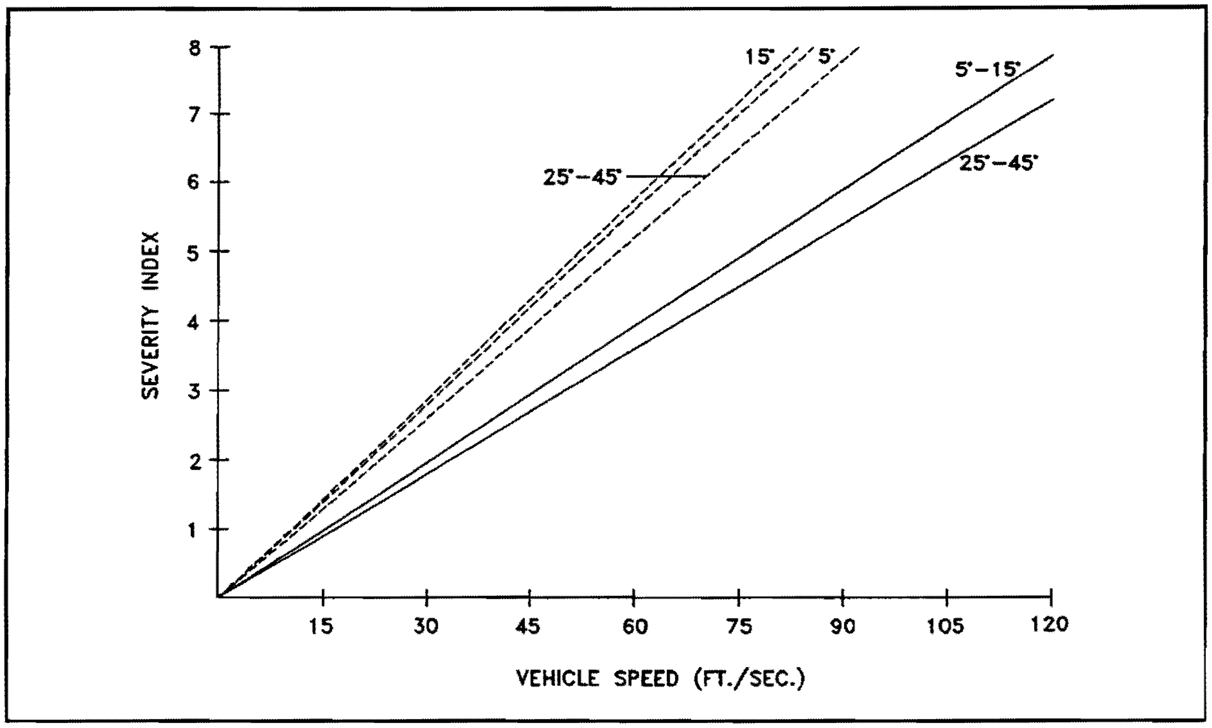


FIGURE B-51. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #5 (Rail Between Third Pair of Posts in Curve)

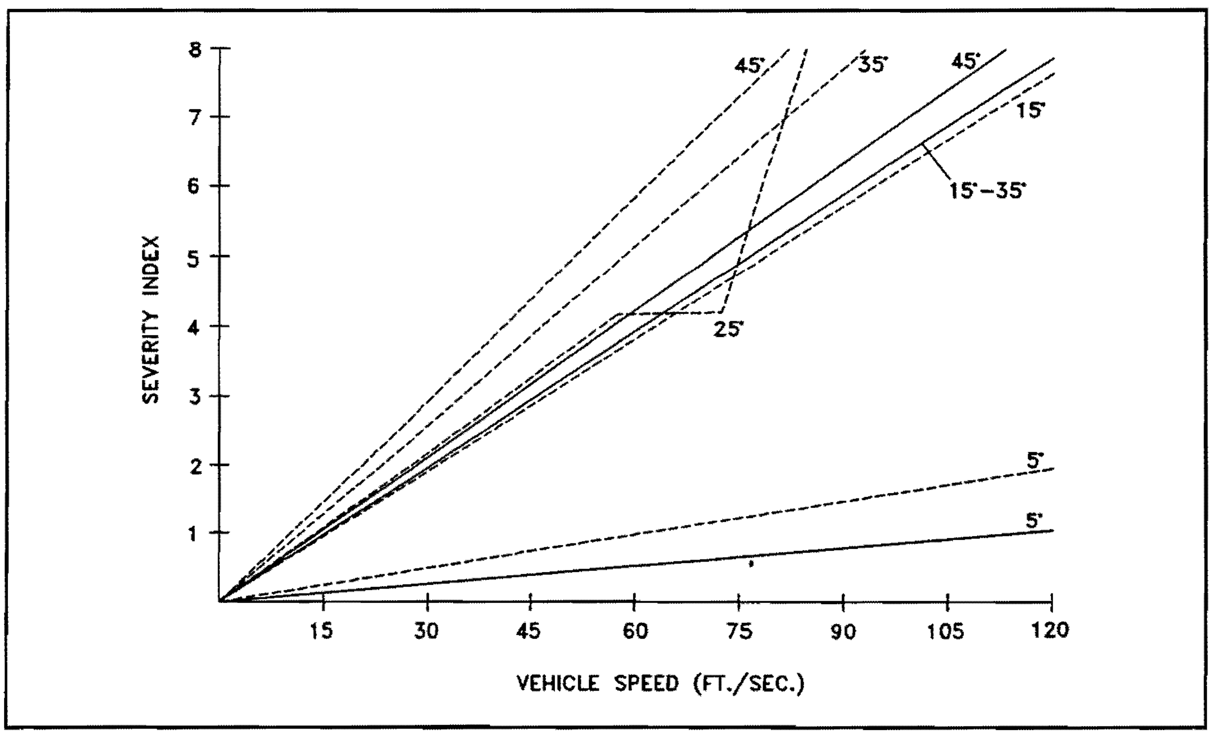


FIGURE B-52. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #6 (Rail Between Last Pair of Posts in Curve)

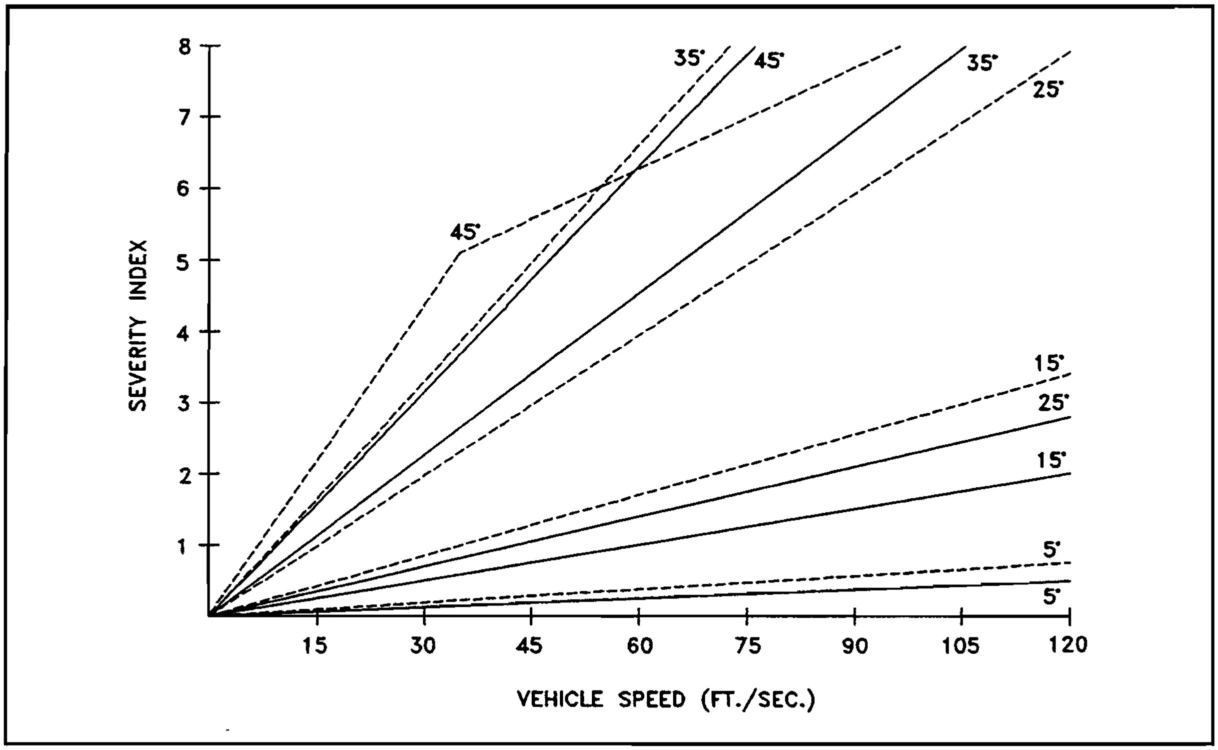


FIGURE B-53. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #7 (25 ft of W-Beam after Curve)

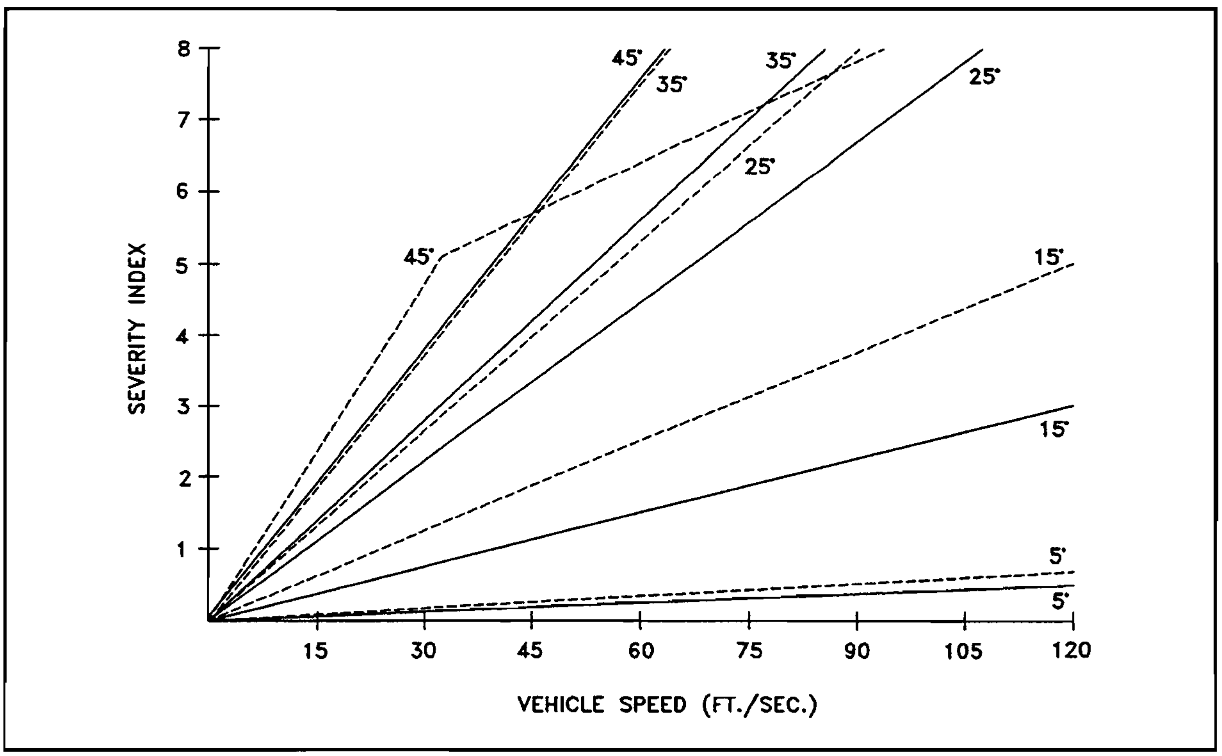


FIGURE B-54. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #8 (Last 12.5 ft of W-Beam Prior to Turndown)

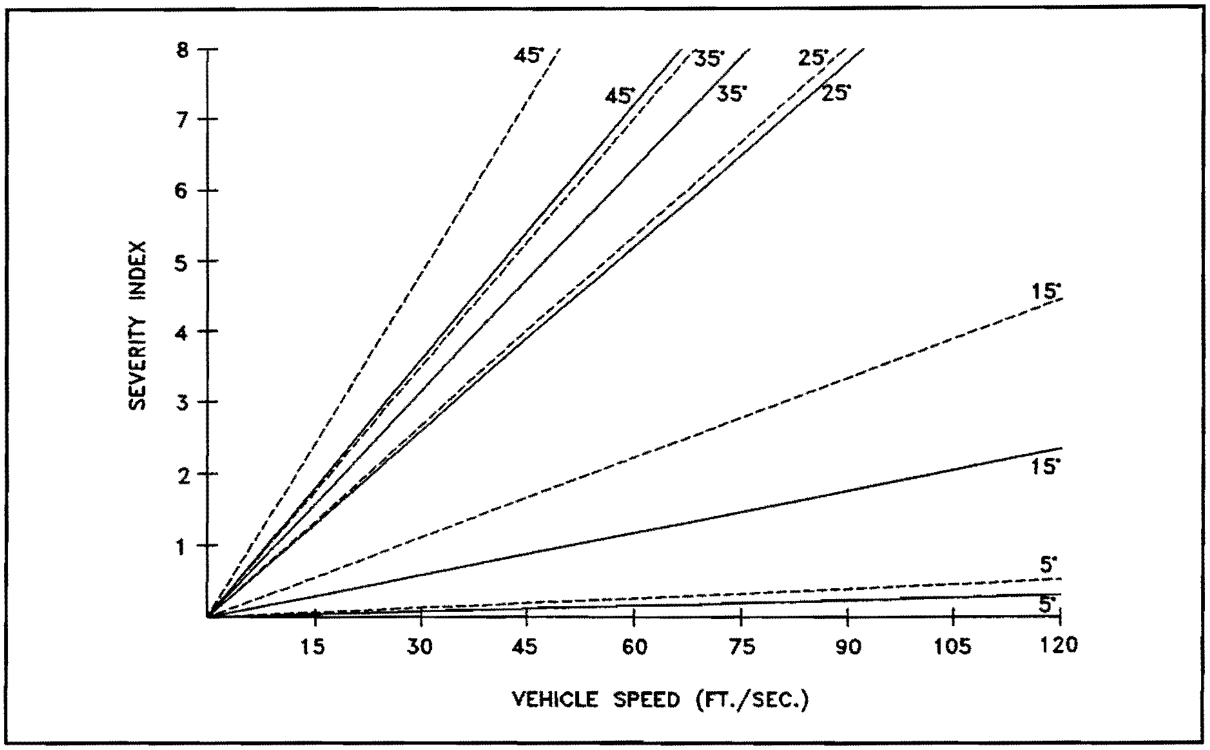


FIGURE B-55. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #9 (12.5 ft Tubular Transition)

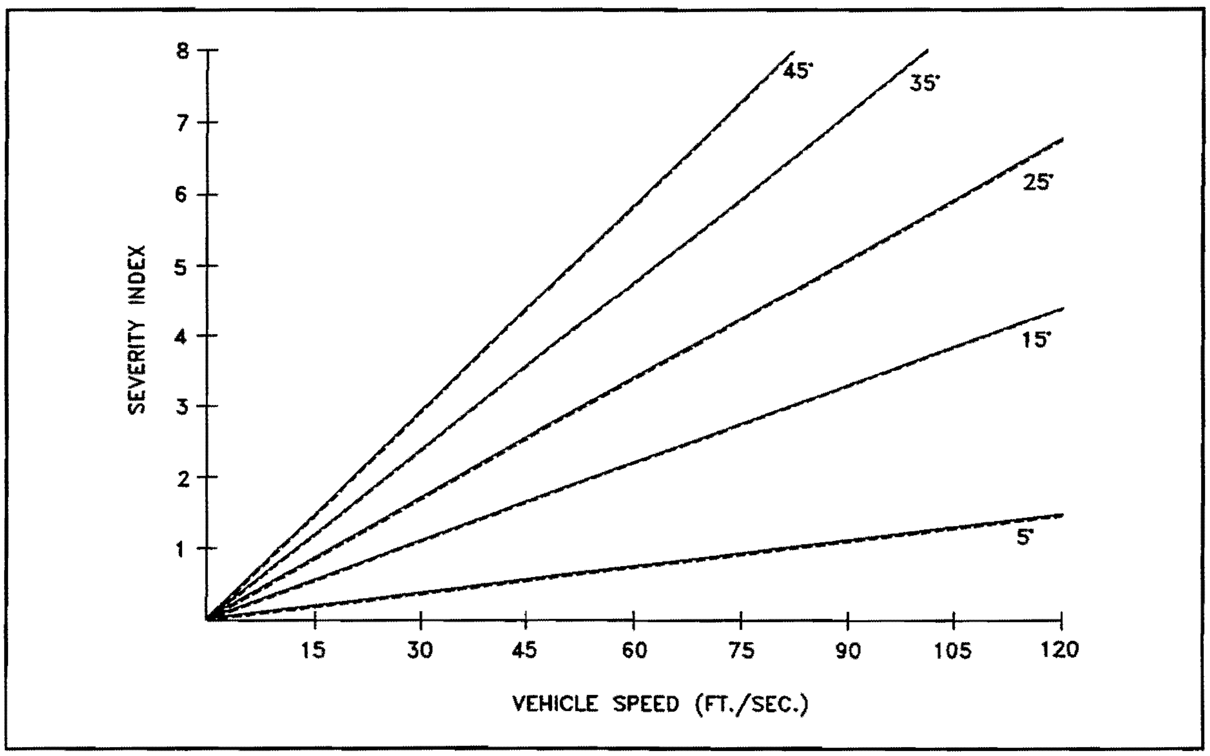


FIGURE B-56. Severity Curve for W-Beam Rail with Curved End Treatment: Hazard #10 (Bridge Wall)

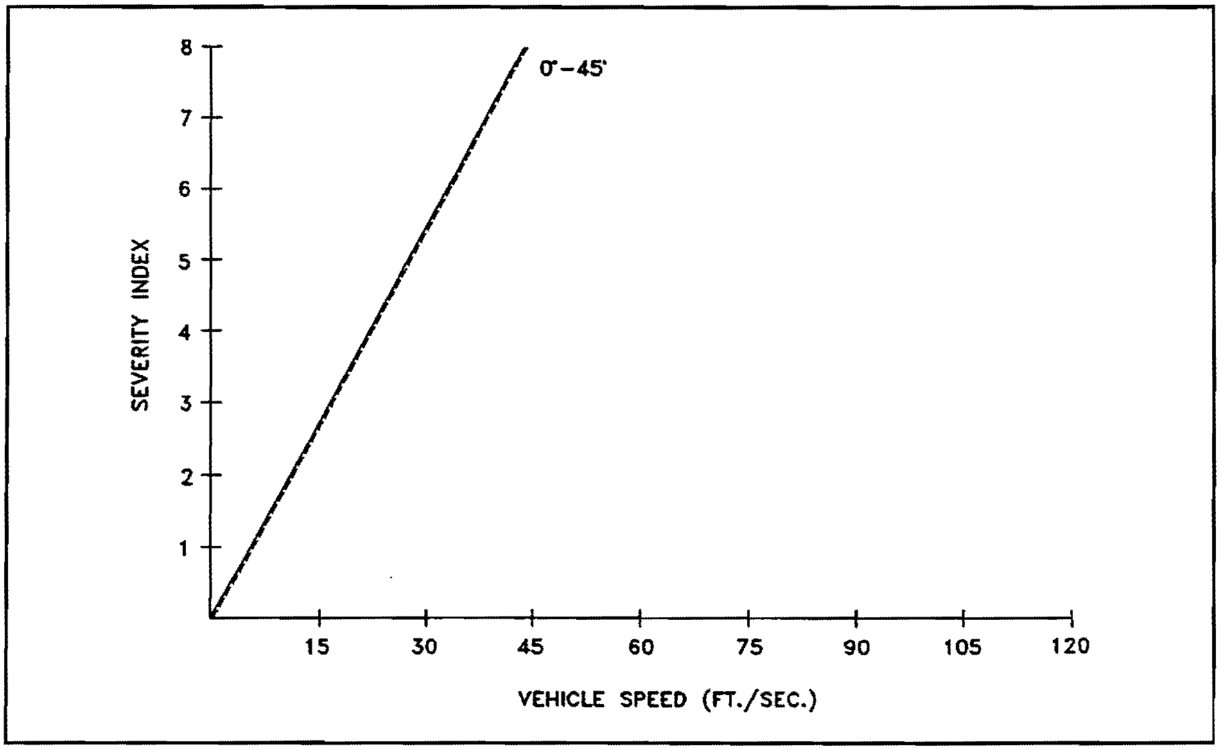


FIGURE B-57. Severity Curve for "Do-Nothing" Option - Untreated Abutment: Hazard #1 (Bridge End)

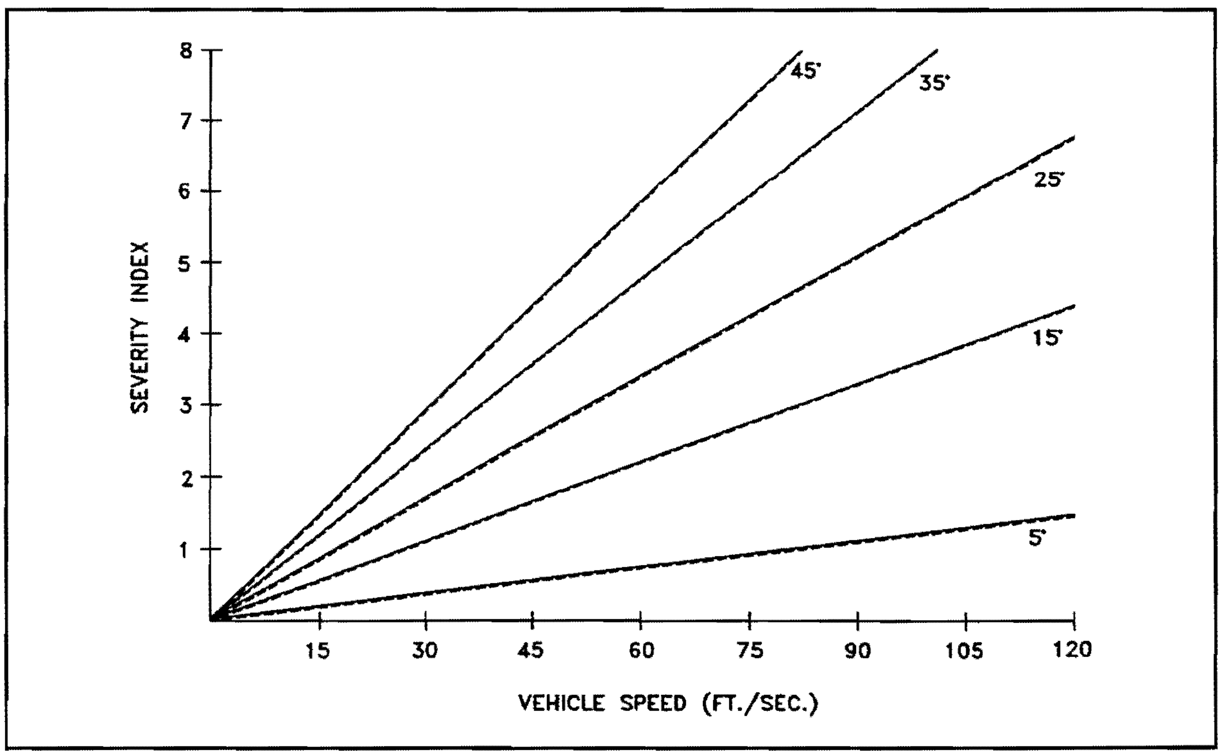


FIGURE B-58. Severity Curve For "Do-Nothing" Option - Untreated Abutment: Hazard #2 (Bridge Wall)

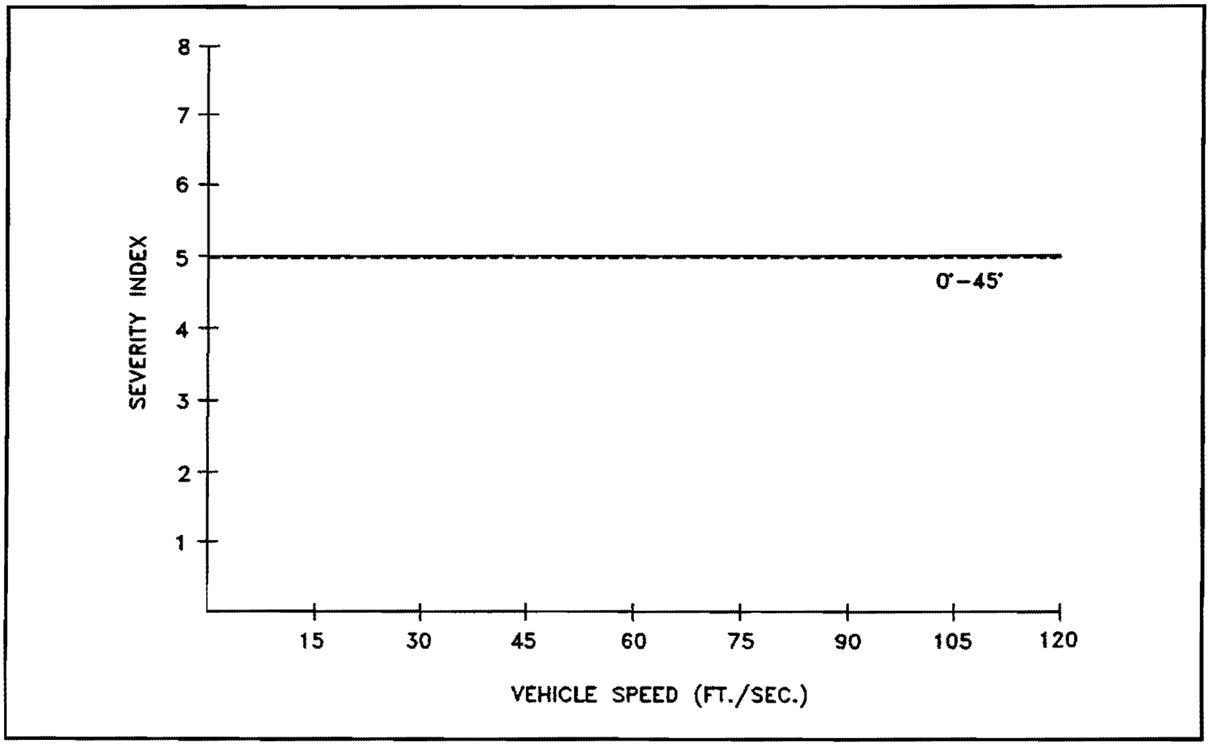


FIGURE B-59. Severity Curve for "Do-Nothing" Option - Untreated Abutment: Hazard #3 (Water Hazard)

```
9.0     3.
1.      2.      4.      500.    0.03    55.
20.0    20.0    20.0    20.0    20.0    20.0    20.0    20.0    20.0    .04
0.0     1375.   3135.   10295.  25350.  56535.  116555. 186150. 281720. 395500.
500000. 0.      0.      0.      0.      0.      00.
5.      14.     2250.   0.350   8.8     6.      18.     4000.   0.550   8.8
8.5     40.     12812.  0.045   11.73   8.5     55.     55121.  0.055   16.77
1.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0     0.0
OPTION 1 45 MPH SHORT RADIUS NESTED W-BEAM SYSTEM; ASSUMED INSTALLED COST = $1000.0 WITH NO SALVAGE VALUE
END OFFSET = 6.0 FT. FLARE RATE = 0.0
7.0     1000.   0.0     0.0
0.0     0.0     1.                      TWELVE AND ONE-HALF FT. TURNDOWN
100.    30.50   0.1     12.5    0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0009  0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.     0.0     11.0    0.0
0.0     0.0733  10.     0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.     0.0     11.0    0.0
0.0     0.0733  10.     0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.0    0.0     11.0    0.0
0.0     0.0733  10.     0.0     11.0    0.0
0.0     0.0733  10.     0.0     11.0    0.0
0.0     0.0     0.0
0.      0.0     1.                      LAST TWELVE AND ONE-HALF FEET OF RAIL BEFORE TURNDOWN
100.    18.0    0.1     12.49   0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0008  0.0
0.0     0.0822  10.0    0.0     11.0    0.0
0.0     0.0822  10.0    0.0     11.0    0.0
0.0     0.0822  10.0    0.0     11.0    0.0
0.0     0.0822  10.0    0.0     11.0    0.0
0.0     0.0822  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0583  10.0    0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00    1.0                     LENGTH OF RAIL BETWEEN FIRST TWO POSTS IN CURVE
101.6   12.0    0.1     0.1     6.25    6.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
```

FIGURE B-60. Input Data for Benefit/Cost Progam

```
0.0009  0.0
0.0     0.0726  10.0    0.0     11.     0.0
0.0     0.0726  10.0    0.0     11.     0.0
0.0     0.0726  10.0    0.0     11.     0.0
0.0     0.0726  10.0    0.0     11.     0.0
0.0     0.0726  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0517  10.0    0.0     11.     0.0
0.0     0.0     0.0
0.0     0.0     1.                       LENGTH OF RAIL BETWEEN MIDDLE POSTS IN CURVE
106.0   7.608   0.1     0.1     6.25    4.39    0.0     0.0     0.0     477819.
477819. 477819. 477819.
0.00104 0.0
0.0     0.1068  10.0    0.0     11.0    0.0
0.0     0.1068  10.0    0.0     11.0    0.0
0.0     0.1068  10.0    0.0     11.0    0.0
0.0     0.1068  10.     0.0     11.0    0.0
0.0     0.1068  10.     0.0     11.0    0.0
0.0     0.0698  10.0    0.0     11.0    0.0
0.0     0.0671  10.0    0.0     11.0    0.0
0.0     0.0616  10.0    0.0     11.0    0.0
0.0     0.0616  10.     0.0     11.0    0.0
0.0     0.0616  10.     0.0     11.0    0.0
0.0     0.0698  10.0    0.0     11.0    0.0
0.0     0.0671  10.0    0.0     11.0    0.0
0.0     0.0616  10.0    0.0     11.0    0.0
0.0     0.0616  10.     0.0     11.0    0.0
0.0     0.0616  10.     0.0     11.0    0.0
0.0     0.0698  10.0    0.0     11.0    0.0
0.0     0.0671  10.0    0.0     11.0    0.0
0.0     0.0616  10.0    0.0     11.0    0.0
0.0     0.0616  10.     0.0     11.0    0.0
0.0     0.0616  10.     0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00    1.0                      LENGTH OF RAIL BETWEEN LAST TWO POSTS IN CURVE
112.0   6.0     0.1     0.1     6.25    1.608   0.0     0.0     0.0     223576.
223576. 223576. 223576.
0.0017  0.0
0.0     0.0495  2.23    0.008   2.35    0.008
0.0     0.0831  10.0    0.0     11.     0.0
0.0     0.1005  10.0    0.0     11.     0.0
0.0     0.1113  10.0    0.0     11.     0.0
0.0     0.1113  4.35    0.0     11.     0.0
0.0     0.0181  0.817   0.0302  1.27    0.0302
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0951  10.0    0.0     11.     0.0
0.0     0.0181  0.817   0.0302  1.27    0.0302
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0866  10.0    0.0     11.     0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0951  10.0    0.0     11.     0.0
0.0     0.0181  0.817   0.0302  1.27    0.0302
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0866  10.0    0.0     11.     0.0
0.0     0.0951  10.0    0.0     11.     0.0
0.0     0.0     0.0
1.0     0.0     1.                      six and one-quarter foot transition
112.1   6.0     6.15    0.5     0.0     0.0     0.0     0.0     7.5     96647.
96647.  96647.  96647.
0.0025  0.0
0.0     0.0158  10.0    0.0     11.     0.0
0.0     0.0079  10.0    0.0     11.     0.0
0.0     0.0631  2.84    0.1640  5.3     0.1640
0.0     0.1377  10.     0.0     11.0    0.0
0.0     0.1660  10.     0.0     11.0    0.0
0.0     0.0102  10.0    0.0     11.0    0.0
0.0     0.0205  10.0    0.0     11.0    0.0
0.0     0.1191  10.0    0.0     11.0    0.0
0.0     0.1191  10.     0.0     11.0    0.0
0.0     0.1191  10.     0.0     11.0    0.0
0.0     0.0102  10.0    0.0     11.0    0.0
0.0     0.0205  10.0    0.0     11.0    0.0
0.0     0.1191  10.0    0.0     11.0    0.0
0.0     0.1191  10.     0.0     11.0    0.0
0.0     0.1191  10.     0.0     11.0    0.0
0.0     0.0102  10.0    0.0     11.0    0.0
0.0     0.0205  10.0    0.0     11.0    0.0
0.0     0.1191  10.0    0.0     11.0    0.0
0.0     0.1191  10.     0.0     11.0    0.0
0.0     0.1191  10.     0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.                  twenty foot bridge wall
118.35  6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 2 60 MPH SHORT RADIUS W-BEAM SYSTEM; ASSUMED INSTALLED COST = $1250.0 WITH NO SALVAGE VALUE
END OFFSET = 6.0 FT. FLARE RATE = 0.0
9.0     1250.0  0.0     0.0
0.0     0.0     1.                      TWENTY-FIVE FT. TURNDOWN
100.    39.0    0.1     24.9    0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0009  0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0      1.              STRAIGHT RAIL BETWEEN CURVE AND TURNDOWN
100.    20.25   0.1     18.65   0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0009  0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00     1.0                    LENGTH OF RAIL BETWEEN FIRST TWO POSTS IN CURVE
100.8   14.75   0.1     0.1     6.25    5.5     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0008  0.0
0.0     0.0580  10.0    0.0     11.     0.0
0.0     0.0580  10.0    0.0     11.     0.0
0.0     0.0580  10.0    0.0     11.     0.0
0.0     0.0580  10.0    0.0     11.     0.0
0.0     0.0580  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0466  10.0    0.0     11.     0.0
0.0     0.0     0.0
0.0     0.0      1.                      LENGTH OF RAIL BETWEEN POSTS 7 AND 8 IN CURVE
104.2   10.17   0.1     0.1     6.25    4.6     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0008  0.0
0.0     0.0758  10.0    0.0     11.0    0.0
0.0     0.0716  10.0    0.0     11.0    0.0
0.0     0.0666  10.0    0.0     11.0    0.0
0.0     0.0666  10.     0.0     11.0    0.0
0.0     0.0666  10.     0.0     11.0    0.0
0.0     0.0555  10.0    0.0     11.0    0.0
0.0     0.0476  10.0    0.0     11.0    0.0
0.0     0.0445  10.0    0.0     11.0    0.0
0.0     0.0445  10.     0.0     11.0    0.0
0.0     0.0445  10.     0.0     11.0    0.0
0.0     0.0555  10.0    0.0     11.0    0.0
0.0     0.0476  10.0    0.0     11.0    0.0
0.0     0.0445  10.0    0.0     11.0    0.0
0.0     0.0445  10.     0.0     11.0    0.0
0.0     0.0445  10.     0.0     11.0    0.0
0.0     0.0555  10.0    0.0     11.0    0.0
0.0     0.0476  10.0    0.0     11.0    0.0
0.0     0.0445  10.0    0.0     11.0    0.0
0.0     0.0445  10.     0.0     11.0    0.0
0.0     0.0445  10.     0.0     11.0    0.0
0.0     0.0     0.0
0.      0.0      1.                      LENGTH OF RAIL BETWEEN POSTS EIGHT AND NINE IN CURVE
108.8   7.08    0.1     0.1     6.25    3.08    0.0     0.0     0.0     395489.
395489. 385489. 385489.
0.001   0.0
0.0     0.0876  10.0    0.0     11.0    0.0
0.0     0.0850  10.0    0.0     11.0    0.0
0.0     0.0833  10.0    0.0     11.0    0.0
0.0     0.0833  10.0    0.0     11.0    0.0
0.0     0.0833  10.0    0.0     11.0    0.0
0.0     0.0683  10.0    0.0     11.0    0.0
0.0     0.0650  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0683  10.0    0.0     11.0    0.0
0.0     0.0650  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0683  10.0    0.0     11.0    0.0
0.0     0.0650  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0635  10.0    0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00     1.0                     LENGTH OF RAIL BETWEEN LAST TWO POSTS IN CURVE
114.25  6.0     0.1     0.1     6.25    1.08    0.0     0.0     0.0     189650.
189650. 189650. 189650.
0.0022  0.0
0.0     0.0125  10.0    0.0     11.     0.0
0.0     0.0741  10.0    0.0     11.     0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0933  10.0    0.0     11.     0.0
0.0     0.1187  10.0    0.0     11.     0.0
0.0     0.1187  4.35    0.0     11.     0.0
0.0     0.0233  10.0    0.0     11.     0.0
0.0     0.0641  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0233  10.0    0.0     11.     0.0
0.0     0.0641  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0233  10.0    0.0     11.     0.0
0.0     0.0641  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0914  10.0    0.0     11.     0.0
0.0     0.0     0.0
1.0     0.00     1.0                     LENGTH OF RAIL BETWEEN TRANSITION AND CURVE
114.25  6.0     6.15    0.1     0.0     0.0     0.0     0.0     0.0      92425.
92425.  92425.  92425.
0.0028  0.0
0.0     0.0063  10.0    0.0     11.0    0.0
0.0     0.0283  10.0    0.0     11.0    0.0
0.0     0.0661  10.0    0.0     11.0    0.0
0.0     0.1100  10.0    0.0     11.0    0.0
0.0     0.1457  5.1     0.047   5.57    0.047
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.0     0.0      1.                      LAST TWELVE AND ONE-HALF FT. OF RAIL BETWEEN CURVE AND ABUTMENT AND
ABUTMENT
120.50  6.0     12.4    0.5     0.0     0.0     0.0     0.0     7.5      96647.
96647.  96647.  96647.
0.0019  0.0
0.0     0.0044  10.0    0.0     11.0    0.0
0.0     0.0370  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1171  10.     0.0     11.0    0.0
0.0     0.1614  10.     0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.     0.0     11.0    0.0
0.0     0.1200  10.     0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.     0.0     11.0    0.0
0.0     0.1200  10.     0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.     0.0     11.0    0.0
0.0     0.1200  10.     0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.                  twenty foot bridge wall
133.0   6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 3 60 MPH SHORT RADIUS THRIE BEAM SYSTEM; ASSUMED INSTALLED COST = $3500.0 WITH NO SALVAGE VALUE
END OFFSET = 6.0 FT. FLARE RATE = 0.0
10.0    3500.0  0.0     0.0
0.0     0.0     1.                      TWELVE AND ONE-HALF FT. TURNDOWN
100.    39.0    0.1     12.5    0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0014  0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0     0.0
0.      0.0     1.                      LAST TWELVE AND ONE HALF FEET OF RAIL BEFORE TURNDOWN
100.    32.73   0.1     6.25    0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0014  0.0
0.0     0.1333  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.                       TWELVE AND ONE HALF FT. OF RAIL BETWEEN CURVE AND CLOSER POSTS NEAR
TURNDOWN
100.    20.25   0.1     12.5    0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0014  0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0796  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00     1.0                     LENGTH OF RAIL BETWEEN FIRST TWO POSTS IN CURVE(NODES 33&41)
100.8   14.75   0.1     0.1     6.25    5.5     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0011  0.0
0.0     0.0666  10.0    0.0     11.     0.0
0.0     0.0666  10.0    0.0     11.     0.0
0.0     0.0666  10.0    0.0     11.     0.0
0.0     0.0666  10.0    0.0     11.     0.0
0.0     0.0666  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
0.0     0.0485  10.0    0.0     11.     0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0      0.0485  10.0    0.0     11.     0.0
0.0      0.0485  10.0    0.0     11.     0.0
0.0      0.0485  10.0    0.0     11.     0.0
0.0      0.0485  10.0    0.0     11.     0.0
0.0      0.0485  10.0    0.0     11.     0.0
0.0      0.0485  10.0    0.0     11.     0.0
0.0      0.0     0.0
0.0      0.0     1.                       LENGTH OF RAIL BETWEEN POSTS 7 AND 8 IN CURVE(NODES 41&49)
104.2    10.17   0.1     0.1     6.25    4.6     0.0     0.0     0.0     541120.
541120.  541120. 541120.
0.0014   0.0
0.0      0.0818  10.0    0.0     11.0    0.0
0.0      0.0745  10.0    0.0     11.0    0.0
0.0      0.0728  10.0    0.0     11.0    0.0
0.0      0.0728  10.     0.0     11.0    0.0
0.0      0.0728  10.     0.0     11.0    0.0
0.0      0.0595  10.0    0.0     11.0    0.0
0.0      0.0491  10.0    0.0     11.0    0.0
0.0      0.0468  10.0    0.0     11.0    0.0
0.0      0.0468  10.     0.0     11.0    0.0
0.0      0.0468  10.     0.0     11.0    0.0
0.0      0.0595  10.0    0.0     11.0    0.0
0.0      0.0491  10.0    0.0     11.0    0.0
0.0      0.0468  10.0    0.0     11.0    0.0
0.0      0.0468  10.     0.0     11.0    0.0
0.0      0.0468  10.     0.0     11.0    0.0
0.0      0.0595  10.0    0.0     11.0    0.0
0.0      0.0491  10.0    0.0     11.0    0.0
0.0      0.0468  10.0    0.0     11.0    0.0
0.0      0.0468  10.     0.0     11.0    0.0
0.0      0.0468  10.     0.0     11.0    0.0
0.0      0.0     0.0
0.       0.0     1.                       LENGTH OF RAIL BETWEEN POSTS EIGHT AND NINE IN CURVE(NODES 49&57)
108.8    7.08    0.1     0.1     6.25    3.08    0.0     0.0     0.0     395489.
395489.  385489. 385489.
0.0015   0.0
0.0      0.0868  10.0    0.0     11.0    0.0
0.0      0.0941  10.0    0.0     11.0    0.0
0.0      0.0895  10.0    0.0     11.0    0.0
0.0      0.0895  10.0    0.0     11.0    0.0
0.0      0.0895  10.0    0.0     11.0    0.0
0.0      0.0710  10.0    0.0     11.0    0.0
0.0      0.0691  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0710  10.0    0.0     11.0    0.0
0.0      0.0691  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0710  10.0    0.0     11.0    0.0
0.0      0.0691  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0635  10.0    0.0     11.0    0.0
0.0      0.0     0.0
0.0      0.00    1.0                      LENGTH OF RAIL BETWEEN LAST TWO POSTS IN CURVE(NODES 57&65)
114.25   6.0     0.1     0.1     6.25    1.08    0.0     0.0     0.0     189646.
189646.  189646. 189646.
0.0034   0.0
0.0      0.0425  10.0    0.0     11.     0.0
0.0      0.0666  10.0    0.0     11.     0.0
0.0      0.0876  10.0    0.0     11.     0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.1022  10.0    0.0     11.     0.0
0.0     0.1108  10.0    0.0     11.     0.0
0.0     0.0186  10.0    0.0     11.     0.0
0.0     0.0701  10.0    0.0     11.     0.0
0.0     0.0701  10.0    0.0     11.     0.0
0.0     0.0800  10.0    0.0     11.     0.0
0.0     0.0848  10.0    0.0     11.     0.0
0.0     0.0186  10.0    0.0     11.     0.0
0.0     0.0701  10.0    0.0     11.     0.0
0.0     0.0701  10.0    0.0     11.     0.0
0.0     0.0800  10.0    0.0     11.     0.0
0.0     0.0848  10.0    0.0     11.     0.0
0.0     0.0186  10.0    0.0     11.     0.0
0.0     0.0701  10.0    0.0     11.     0.0
0.0     0.0701  10.0    0.0     11.     0.0
0.0     0.0800  10.0    0.0     11.     0.0
0.0     0.0848  10.0    0.0     11.     0.0
0.0     0.0     0.0
1.0     0.0     1.           RAIL BETWEEN CURVE AND NESTED TRANSITION SECTION
114.35  6.0     6.25    0.5     0.0     0.0     0.0     0.0     7.5     96642.
96642.  96642.  96642.
0.0090  0.0
0.0     0.0141  10.0    0.0     11.0    0.0
0.0     0.0368  10.0    0.0     11.0    0.0
0.0     0.0651  2.28    0.108   3.36    0.136
0.0     0.0718  10.0    0.0     11.0    0.0
0.0     0.0902  10.0    0.0     11.0    0.0
0.0     0.0090  10.0    0.0     11.0    0.0
0.0     0.0216  10.0    0.0     11.0    0.0
0.0     0.0736  10.0    0.0     11.0    0.0
0.0     0.0802  10.     0.0     11.0    0.0
0.0     0.1014  10.     0.0     11.0    0.0
0.0     0.0090  10.0    0.0     11.0    0.0
0.0     0.0216  10.0    0.0     11.0    0.0
0.0     0.0736  10.0    0.0     11.0    0.0
0.0     0.0802  10.     0.0     11.0    0.0
0.0     0.1014  10.     0.0     11.0    0.0
0.0     0.0090  10.0    0.0     11.0    0.0
0.0     0.0216  10.0    0.0     11.0    0.0
0.0     0.0736  10.0    0.0     11.0    0.0
0.0     0.0802  10.     0.0     11.0    0.0
0.0     0.1014  10.     0.0     11.0    0.0
0.0     0.0     0.0
1.0     0.0     1.             7.8' NESTED THRIE BEAM TRANSITION
120.60  6.0     7.80    0.5     0.0     0.0     0.0     0.0     7.5     96642.
96642.  96642.  96642.
0.0090  0.0
0.0     0.0158  10.0    0.0     11.0    0.0
0.0     0.0344  1.55    .116    3.30    .116
0.0     0.0640  2.88    .139    4.97    .139
0.0     0.1277  10.     0.0     11.0    0.0
0.0     0.1606  10.     0.0     11.0    0.0
0.0     0.0108  10.0    0.0     11.0    0.0
0.0     0.0111  .500    .141    2.62    .141
0.0     0.0426  1.92    .399    5.91    .399
0.0     0.0832  3.74    .484    11.0    0.0
0.0     0.1385  4.85    .047    5.32    .047
0.0     0.0108  10.0    0.0     11.0    0.0
0.0     0.0111  .500    .141    2.62    .141
0.0     0.0426  1.92    .356    7.26    .356
0.0     0.0832  3.74    .484    11.0    0.0
0.0     0.1385  4.85    .047    5.32    .047
0.0     0.0108  10.0    0.0     11.0    0.0
0.0     0.0111  .500    .141    2.62    .141
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0426  1.92    .356    7.26    .356
0.0     0.0832  3.74    .484    11.0    0.0
0.0     0.1385  4.85    .047    5.32    .047
0.0     0.0     0.0
1.      0.0     1.              twenty foot bridge wall
128.41  6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 4  TREND: ASSUME INSTALLED COST = $5000 WITH NO SALVAGE VALUE
END OFFSET = 6.0 FT. FLARE RATE = 0.0
3.0     5000.0  0.0     0.0
0.0     0.0     1.              END OF TREND
100.    4.5     0.1     3.0     0.0     0.0     0.0     0.0     0.0     557473.
557473. 557473. 557473.
0.0020  0.0
0.0     0.0778  10.0    0.0     11.0    0.0
0.0     0.0778  10.0    0.0     11.0    0.0
0.0     0.0778  10.0    0.0     11.0    0.0
0.0     0.0778  10.     0.0     11.0    0.0
0.0     0.0778  10.     0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.     0.0     11.0    0.0
0.0     0.0600  10.     0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.     0.0     11.0    0.0
0.0     0.0600  10.     0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.     0.0     11.0    0.0
0.0     0.0600  10.     0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.          18' OF TREND ALONG MAIN ROADWAY
100.2   4.5     17.8    3.0     0.0     0.0     0.0     0.0     0.0     96647.
96647.  96647.  96647.
0.0138  0.0
0.0     0.0054  10.0    0.0     11.0    0.0
0.0     0.0393  10.0    0.0     11.0    0.0
0.0     0.0596  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.1000  10.0    0.0     11.0    0.0
0.0     0.1457  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0196  10.0    0.0     11.0    0.0
0.0     0.0616  10.0    0.0     11.0    0.0
0.0     0.0824  10.0    0.0     11.0    0.0
0.0     0.1188  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0196  10.0    0.0     11.0    0.0
0.0     0.0616  10.0    0.0     11.0    0.0
0.0     0.0824  10.0    0.0     11.0    0.0
0.0     0.1188  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0196  10.0    0.0     11.0    0.0
0.0     0.0616  10.0    0.0     11.0    0.0
0.0     0.0824  10.0    0.0     11.0    0.0
0.0     0.1188  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.                     twenty foot bridge wall
118.1   6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 5 SAND TUBS; ESTIMATED INSTALLED COST = $2400 (12 TUBS) ($200/TUB INSTALLED) NO SALVAGE VALUE
END OFFSET = 6 FT. FLARE RATE = 0
6.0     2400.   0.0     0.0
0.      0.0     1.                      LEADING TUB OF SAND INERTIAL TREATMENT
100.    4.5     2.5     3.0     0.0     0.0     0.0     0.0     0.0     96000.
96000.  96000.  96000.
0.025   0.0
0.0     0.0121  10.0    0.0     11.0    0.0
0.0     0.0364  10.0    0.0     11.0    0.0
0.0     0.0562  10.0    0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.0    0.0     11.0    0.0
0.0     0.0364  10.0    0.0     11.0    0.0
0.0     0.0562  10.0    0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.0    0.0     11.0    0.0
0.0     0.0364  10.0    0.0     11.0    0.0
0.0     0.0562  10.0    0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.0    0.0     11.0    0.0
0.0     0.0364  10.0    0.0     11.0    0.0
0.0     0.0562  10.0    0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
0.      0.0     1.      SECOND TUB AND THIRD SET OF TUBS IN INERTIAL TREATMENT
103.5   2.5     4.5     6.5     0.0     0.0     0.0     0.0     0.0     96000.
96000.  96000.  96000.
0.025   0.0
0.0     0.078   4.68    0.15    10.     0.0
0.0     0.078   4.68    0.15    10.     0.0
0.0     0.070   4.20    0.15    10.     0.0
0.0     0.070   3.20    0.0     10.     0.0
0.0     0.070   3.20    0.0     10.     0.0
0.0     0.073   3.285   0.15    10.     0.0
0.0     0.073   3.285   0.15    10.     0.0
0.0     0.073   3.285   0.15    10.     0.0
0.0     0.073   3.285   0.15    10.     0.0
0.0     0.073   3.285   0.0     10.     0.0
0.0     0.090   4.1     0.15    10.     0.0
0.0     0.090   4.1     0.15    10.     0.0
0.0     0.090   4.1     0.15    10.     0.0
0.0     0.090   4.1     0.15    10.     0.0
0.0     0.090   4.1     0.0     10.     0.0
0.0     0.150   10.0    0.0     11.     0.0
0.0     0.150   10.0    0.0     11.     0.0
0.0     0.150   10.0    0.0     11.     0.0
0.0     0.150   10.0    0.0     11.     0.0
0.0     0.150   10.0    0.0     11.     0.0
0.0     0.0     0.0
0.      0.0     1.                      FOURTH AND FIFTH SET OF TUBS IN SAND INERTIAL TREATMENT
110.50  2.5     4.5     6.5     0.0     0.0     0.0     0.0     0.0     88000.
88000.  88000.  88000.
0.025   0.0
0.0     0.0531  7.5     0.00    0.0     0.0          5 DEG.  * SEVERITIES FOR THIS TUB
0.0     0.080   4.80    0.15    10.     0.0         15 DEG.    ARE CORRECT
0.0     0.080   4.80    0.15    10.     0.0         25 DEG.
0.0     0.080   4.80    0.15    10.     0.0         35 DEG.
0.0     0.080   3.60    0.0     10.     0.0         45 DEG.
0.0     0.0531  7.50    0.0     0.0     0.0          5 DEG.
0.0     0.089   4.01    0.15    10.     0.0         15 DEG.
0.0     0.089   4.01    0.15    10.     0.0         25 DEG.
0.0     0.089   4.01    0.15    10.     0.0         35 DEG.
0.0     0.089   4.01    0.0     10.     0.0         45 DEG.
0.0     0.0531  7.50    0.0     0.0     0.0          5 DEG.
0.0     0.110   6.0     0.15    10.     0.0         15 DEG.
0.0     0.110   6.0     0.15    10.     0.0         25 DEG.
0.0     0.110   6.0     0.15    10.     0.0         35 DEG.
0.0     0.110   6.0     0.15    10.     0.0         45 DEG.
0.0     0.0531  7.50    0.0     0.0     0.0          5 DEG.
0.0     0.150   10.0    0.0     11.     0.0         15 DEG.
0.0     0.150   10.0    0.0     11.     0.0         25 DEG.
0.0     0.150   10.0    0.0     11.     0.0         35 DEG.
0.0     0.150   10.0    0.0     11.     0.0         45 DEG.
0.0     0.0     0.0
0.      0.0     1.                              SIXTH SET OF TUBS IN SAND INERTIAL TREATMENT
117.50  2.5     1.00    6.5     0.0     0.0     0.0     0.0     0.0     48000.
48000.  48000.  48000.
0.025   0.0
0.0     0.0531  7.50    0.0     11.     0.0          5 DEG.  * SEVERITIES FOR THIS TUB
0.0     0.0754  7.50    0.0     11.     0.0         15 DEG.    ARE CORRECT
0.0     0.083   5.0     0.15    10.     0.0         25 DEG.
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.083   5.0     0.15    10.     0.0           35 DEG.
0.0     0.083   5.0     0.15    10.     0.0           45 DEG.
0.0     0.0531  7.50    0.0     11.     0.0            5 DEG.
0.0     0.0754  7.50    0.0     11.     0.0           15 DEG.
0.0     0.106   4.77    0.15    10.     0.0           25 DEG.
0.0     0.106   4.77    0.15    10.     0.0           35 DEG.
0.0     0.106   4.77    0.15    10.     0.0           45 DEG.
0.0     0.0531  7.50    0.0     11.     0.0            5 DEG.
0.0     0.0754  7.50    0.0     11.     0.0           15 DEG.
0.0     0.130   6.0     0.15    10.     0.0           25 DEG.
0.0     0.130   6.0     0.15    10.     0.0           35 DEG.
0.0     0.130   6.0     0.15    10.     0.0           45 DEG.
0.0     0.0531  7.50    0.0     11.     0.0            5 DEG.
0.0     0.0754  7.50    0.0     11.     0.0           15 DEG.
0.0     0.15    10.0    0.0     11.     0.0           25 DEG.
0.0     0.15    10.0    0.0     11.     0.0           35 DEG.
0.0     0.15    10.0    0.0     11.     0.0           45 DEG.
0.0     0.0     0.0
1.      0.0     1.                            SEVENTH SET OF TUBS IN SAND INERTIAL TREATMENT
121.0   4.5     2.00    6.5     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.1     0.0
0.0     0.0531  7.50    0.0     11.0    0.0            5 DEG.  * SEVERITIES FOR THIS TUB
0.0     0.0754  7.50    0.0     11.0    0.0           15 DEG.    ARE CORRECT
0.0     0.094   7.50    0.0     11.0    0.0           25 DEG.
0.0     0.104   6.25    0.15    10.0    0.0           35 DEG.
0.0     0.104   6.25    0.15    10.0    0.0           45 DEG.
0.0     0.0531  7.50    0.0     11.0    0.0            5 DEG.
0.0     0.0754  7.50    0.0     11.0    0.0           15 DEG.
0.0     0.094   7.50    0.0     11.0    0.0           25 DEG.
0.0     0.133   6.0     0.15    11.0    0.0           35 DEG.
0.0     0.133   6.0     0.15    11.0    0.0           45 DEG.
0.0     0.0531  7.50    0.0     11.0    0.0            5 DEG.
0.0     0.0754  7.50    0.0     11.0    0.0           15 DEG.
0.0     0.094   7.50    0.0     11.0    0.0           25 DEG.
0.0     0.15    10.     0.0     11.0    0.0           35 DEG.
0.0     0.15    10.     0.0     11.0    0.0           45 DEG.
0.0     0.0531  7.50    0.0     11.0    0.0            5 DEG.
0.0     0.0754  7.50    0.0     11.0    0.0           15 DEG.
0.0     0.094   7.50    0.0     11.0    0.0           25 DEG.
0.0     0.15    10.     0.0     11.0    0.0           35 DEG.
0.0     0.15    10.     0.0     11.0    0.0           45 DEG.
0.0     0.0     0.0
1.      0.0     1.                      twenty foot bridge wall
123.1   6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 6 W-BEAM RAIL WITH TURN DOWN; ASSUMED INSTALLED COST = $900 WITH NO SALVAGE VALUE
END OFFSET = 6.0 FT. FLARE RATE = 0.0
6.0     900.    0.0     0.0
0.0     1.0     1.                   extreme end of turndown
100.    6.0     0.1     2.0     0.0     0.0     0.0     0.0     0.0     547607.
547607. 547607. 547607.
0.001   0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   4.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.111   5.0     0.2     10.0    0.0
0.0     0.0     0.0
0.      1.0     1.              first 9.0 feet of turndown
100.11  6.0     8.89    1.0     0.0     0.0     0.0     0.0     0.0     547607.
547607. 547607. 547607.
0.001   0.0
0.0     0.0333  1.0     0.36    6.4     0.1433
0.0     0.0667  2.0     0.2933  6.4     0.1433
0.0     0.10    3.0     0.22667 6.4     0.1433
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.0333  1.0     0.36    6.4     0.1433
0.0     0.0677  2.0     0.2933  6.4     0.1433
0.0     0.10    3.0     0.22667 6.4     0.1433
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.0333  1.0     0.36    6.4     0.1433
0.0     0.0667  2.0     0.2933  6.4     0.1433
0.0     0.10    3.0     0.22667 6.4     0.1433
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.0333  1.0     0.36    6.4     0.1433
0.0     0.0667  2.0     0.2933  6.4     0.1433
0.0     0.10    3.0     0.22667 6.4     0.1433
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.14222 10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.             LAST 3.25 ft. of turndown and 37.5 ft. of w-beam
109.1   6.0     40.65   .5      0.0     0.0     0.0     0.0     0.0     92425.
92425.  92425.  92425.
0.0028  0.0
0.0     0.0063  10.0    0.0     11.0    0.0
0.0     0.0283  10.0    0.0     11.0    0.0
0.0     0.0661  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.1100  10.0    0.0     11.0    0.0
0.0     0.1457  5.1     0.047   5.57    0.047
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.              last 12.5 ft. of w-beam before tubulat transition
150.1   6.0     12.4    .5      0.0     0.0     0.0     0.0     0.0     92425.
92425.  92425.  92425.
0.0028  0.0
0.0     0.0056  10.0    0.0     11.0    0.0
0.0     0.0416  10.0    0.0     11.0    0.0
0.0     0.0883  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.1574  5.1     0.047   5.57    0.047
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.               12.5' OF TUBULAR TRANSITION(SEVERITIES FROM CURVED W-BEAM SYSTEM)
162.6   6.0     12.4    .5      0.0     0.0     0.0     0.0     0.0     96647.
96647.  96647.  96647.
0.0017  0.0
0.0     0.0044  10.0    0.0     11.0    0.0
0.0     0.0370  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1171  10.0    0.0     11.0    0.0
0.0     0.1614  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.              twenty foot bridge wall
175.1   6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 7 WBEAM WITH ET-2000: ASSUMED INSTALLED COST = $1500 WITH NO SALVAGE VALUE
END OFFSET = 6.0 FT. FLARE RATE = 0.0
5.0     1500.0  0.0     0.0
0.0     1.0     1.              ET-2000 EXTRUDER
100.    5.0     0.1     2.0     0.0     0.0     0.0     0.0     0.0     547607.
547607. 547607. 547607.
0.00056 0.0
0.0     0.0720  10.0    0.0     11.0    0.0
0.0     0.0720  10.0    0.0     11.0    0.0
0.0     0.0720  10.0    0.0     11.0    0.0
0.0     0.0720  10.     0.0     11.0    0.0
0.0     0.0720  10.     0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.     0.0     11.0    0.0
0.0     0.0488  10.     0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.     0.0     11.0    0.0
0.0     0.0488  10.     0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.0    0.0     11.0    0.0
0.0     0.0488  10.     0.0     11.0    0.0
0.0     0.0488  10.     0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.              37.5' OF W-BEAM AFTER EXTRUDER
100.2   6.0     37.3    .5      0.0     0.0     0.0     0.0     0.0     92425.
92425.  92425.  92425.
0.0028  0.0
0.0     0.0063  10.0    0.0     11.0    0.0
0.0     0.0283  10.0    0.0     11.0    0.0
0.0     0.0661  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.1100  10.0    0.0     11.0    0.0
0.0     0.1457  5.1     0.047   5.57    0.047
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.              LAST 12.5 FT. OF W-BEAM BEFORE TUBULAR TRANSITION
137.6   6.0     12.4    .5      0.0     0.0     0.0     0.0     0.0     92425.
92425.  92425.  92425.
0.0028  0.0
0.0     0.0056  10.0    0.0     11.0    0.0
0.0     0.0416  10.0    0.0     11.0    0.0
0.0     0.0883  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.1574  5.1     0.047   5.57    0.047
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.               12.5' OF TUBULAR TRANSITION(SEVERITIES FROM CURVED W-BEAM SYSTEM)
150.1   6.0     12.4    .5      0.0     0.0     0.0     0.0     0.0     96647.
96647.  96647.  96647.
0.0017  0.0
0.0     0.0044  10.0    0.0     11.0    0.0
0.0     0.0370  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1171  10.0    0.0     11.0    0.0
0.0     0.1614  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.                   twenty foot bridge wall
162.6   6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 8 W-BEAM RAIL WITH CURVED END TREATMENT; ASSUMED INSTALLED COST = $1750.0 WITH NO SALVAGE VALUE
END OFFSET = 6.0 FT. FLARE RATE = 0.0
10.0    1750.0  0.0     0.0
0.0     0.0     1.                      TWELVE AND ONE-HALF FT. TURNDOWN
100.    45.25   0.1     12.5    0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0009  0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.1333  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.0    0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0808  10.     0.0     11.0    0.0
0.0     0.0     0.0
0.      0.0     1.                      25 feet of rail between turndown and CURVE
100.    32.75   0.1     24.99   0.0     0.0     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0009  0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.1333  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0516  10.0    0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00     1.                     LENGTH OF RAIL BETWEEN FIRST TWO POSTS IN CURVE
100.8   14.75   0.1     0.1     6.25    5.5     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0007  0.0
0.0     0.0610  10.0    0.0     11.     0.0
0.0     0.0610  10.0    0.0     11.     0.0
0.0     0.0610  10.0    0.0     11.     0.0
0.0     0.0610  10.0    0.0     11.     0.0
0.0     0.0610  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0455  10.0    0.0     11.     0.0
0.0     0.0     0.0
0.0     0.0      1.                     LENGTH OF RAIL BETWEEN NODES 24 AND 32 IN CURVE
104.2   10.17   0.1     0.1     6.25    4.6     0.0     0.0     0.0     541120.
541120. 541120. 541120.
0.0007  0.0
0.0     0.0763  10.0    0.0     11.0    0.0
0.0     0.0703  10.0    0.0     11.0    0.0
0.0     0.0666  10.0    0.0     11.0    0.0
0.0     0.0666  10.     0.0     11.0    0.0
0.0     0.0666  10.     0.0     11.0    0.0
0.0     0.0575  10.0    0.0     11.0    0.0
0.0     0.0478  10.0    0.0     11.0    0.0
0.0     0.0421  10.0    0.0     11.0    0.0
0.0     0.0421  10.     0.0     11.0    0.0
0.0     0.0421  10.     0.0     11.0    0.0
0.0     0.0575  10.0    0.0     11.0    0.0
0.0     0.0478  10.0    0.0     11.0    0.0
0.0     0.0421  10.0    0.0     11.0    0.0
0.0     0.0421  10.     0.0     11.0    0.0
0.0     0.0421  10.     0.0     11.0    0.0
0.0     0.0575  10.0    0.0     11.0    0.0
0.0     0.0478  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0421  10.0    0.0     11.0    0.0
0.0     0.0421  10.     0.0     11.0    0.0
0.0     0.0421  10.     0.0     11.0    0.0
0.0     0.0     0.0
0.      0.0     1.                      LENGTH OF RAIL BETWEEN NODES 32 AND 40 IN CURVE
108.8   7.08    0.1     0.1     6.25    3.08    0.0     0.0     0.0     395489.
395489. 385489. 385489.
0.0009  0.0
0.0     0.0938  10.0    0.0     11.0    0.0
0.0     0.0961  10.0    0.0     11.0    0.0
0.0     0.0868  10.0    0.0     11.0    0.0
0.0     0.0868  10.0    0.0     11.0    0.0
0.0     0.0868  10.0    0.0     11.0    0.0
0.0     0.0655  10.0    0.0     11.0    0.0
0.0     0.0655  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0655  10.0    0.0     11.0    0.0
0.0     0.0655  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0655  10.0    0.0     11.0    0.0
0.0     0.0655  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0600  10.0    0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00    1.                      LENGTH OF RAIL BETWEEN LAST TWO POSTS IN CURVE
114.25  6.0     0.1     0.1     6.25    1.08    0.0     0.0     0.0     189650.
189650. 189650. 189650.
0.0016  0.0
0.0     0.0163  10.0    0.0     11.     0.0
0.0     0.0636  10.0    0.0     11.     0.0
0.0     0.0725  4.17    0.002   4.2     0.316
0.0     0.0860  10.0    0.0     11.     0.0
0.0     0.0977  4.35    0.0     11.     0.0
0.0     0.0087  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0705  10.0    0.0     11.     0.0
0.0     0.0087  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0705  10.0    0.0     11.     0.0
0.0     0.0087  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0655  10.0    0.0     11.     0.0
0.0     0.0705  10.0    0.0     11.     0.0
0.0     0.0     0.0
1.      0.0     1.                          25.0 OF W-BEAM AFTER CURVE
114.35  6.0     24.99   0.5     0.0     0.0     0.0     0.0     0.0     92425.
92425.  92425.  92425.
0.0028  0.0
0.0     0.0063  10.0    0.0     11.0    0.0
0.0     0.0283  10.0    0.0     11.0    0.0
0.0     0.0661  10.0    0.0     11.0    0.0
0.0     0.1100  10.0    0.0     11.0    0.0
0.0     0.1457  5.1     0.047   5.57    0.047
0.0     0.0041  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0166  10.0    0.0     11.0    0.0
0.0     0.0233  10.0    0.0     11.0    0.0
0.0     0.0757  10.0    0.0     11.0    0.0
0.0     0.1057  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.              LAST 12.5 FT. OF W-BEAM BEFORE TUBULAR TRANSITION
139.35  6.0     12.49   0.5      0.0    0.0      0.0     0.0     0.0     92425.
92425.  92425.  92425.
0.0028  0.0
0.0     0.0056  10.0    0.0     11.0    0.0
0.0     0.0416  10.0    0.0     11.0    0.0
0.0     0.0883  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.1574  5.1     0.047   5.57    0.047
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0041  10.0    0.0     11.0    0.0
0.0     0.0250  10.0    0.0     11.0    0.0
0.0     0.0743  10.0    0.0     11.0    0.0
0.0     0.0937  10.0    0.0     11.0    0.0
0.0     0.1248  10.0    0.0     11.0    0.0
0.0     0.0     0.0
1.      0.0     1.                12.5' OF TUBULAR TRANSITION(SEVERITIES FROM CURVED W-BEAM SYSTEM)
151.85  6.0     12.49   .5      0.0     0.0      0.0     0.0     0.0     96647.
96647.  96647.  96647.
0.0017  0.0
0.0     0.0044  10.0    0.0     11.0    0.0
0.0     0.0370  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1171  10.0    0.0     11.0    0.0
0.0     0.1614  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
0.0     0.0003  10.0    0.0     11.0    0.0
0.0     0.0195  10.0    0.0     11.0    0.0
0.0     0.0896  10.0    0.0     11.0    0.0
0.0     0.1048  10.0    0.0     11.0    0.0
0.0     0.1200  10.0    0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0     0.0
1.      0.0      1.               twenty foot bridge wall
164.35  6.0     19.99   2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
OPTION 9 = "DO NOTHING" OPTION - UNTREATED ABUTMENT; ASSUMENT INSTALLED COST = 0.0
END OFFSET = 6.0., FLARE RATE = 0
3.0     0.0     0.0     0.0
0.0     0.00     1.             END OF BRIDGE ABUTMENT
100.    6.0     0.1     2.      0.0     0.0     0.0     0.0     0.0     6600000.
6600000.6600000.6600000.
0.0004  375000.
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.182   10.     0.0     11.     0.0
0.0     0.0     0.0
1.      0.0      1.               twenty foot bridge wall
100.1   6.0     19.9    2.0     0.0     0.0     0.0     0.0     7.5     76000.
126000. 126000. 126000.
0.01    50000.
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

```
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0121  10.     0.0     11.0    0.0
0.0     0.0364  10.     0.0     11.0    0.0
0.0     0.0562  10.     0.0     11.0    0.0
0.0     0.079   10.     0.0     11.0    0.0
0.0     0.097   10.     0.0     11.0    0.0
0.0     0.0     0.0
0.0     0.00     1.          RIVER
105.    8.1     0.1     30.     0.0     0.0     0.0     0.0     0.0     6600000.
6600000.6600000.6600000.
0.0004  375000.
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     5.0     0.0     5.0     0.0
0.0     0.0     0.0
```

FIGURE B-60. Input Data for Benefit/Cost Progam (Continued)

APPENDIX C

SOCIETAL COST VS. ADT CHARTS

60 MPH SHORT RADIUS DESIGN COMPARED TO 45 MPH SHORT RADIUS DESIGN

APPENDIX C
SOCIETAL COST VS. ADT CHARTS

The following figures show the societal cost versus ADT for the 45 mph short radius design and the 60 mph short radius design for the eight roadway types considered in the analysis. See Section 4.4.1 for further discussion of these curves.

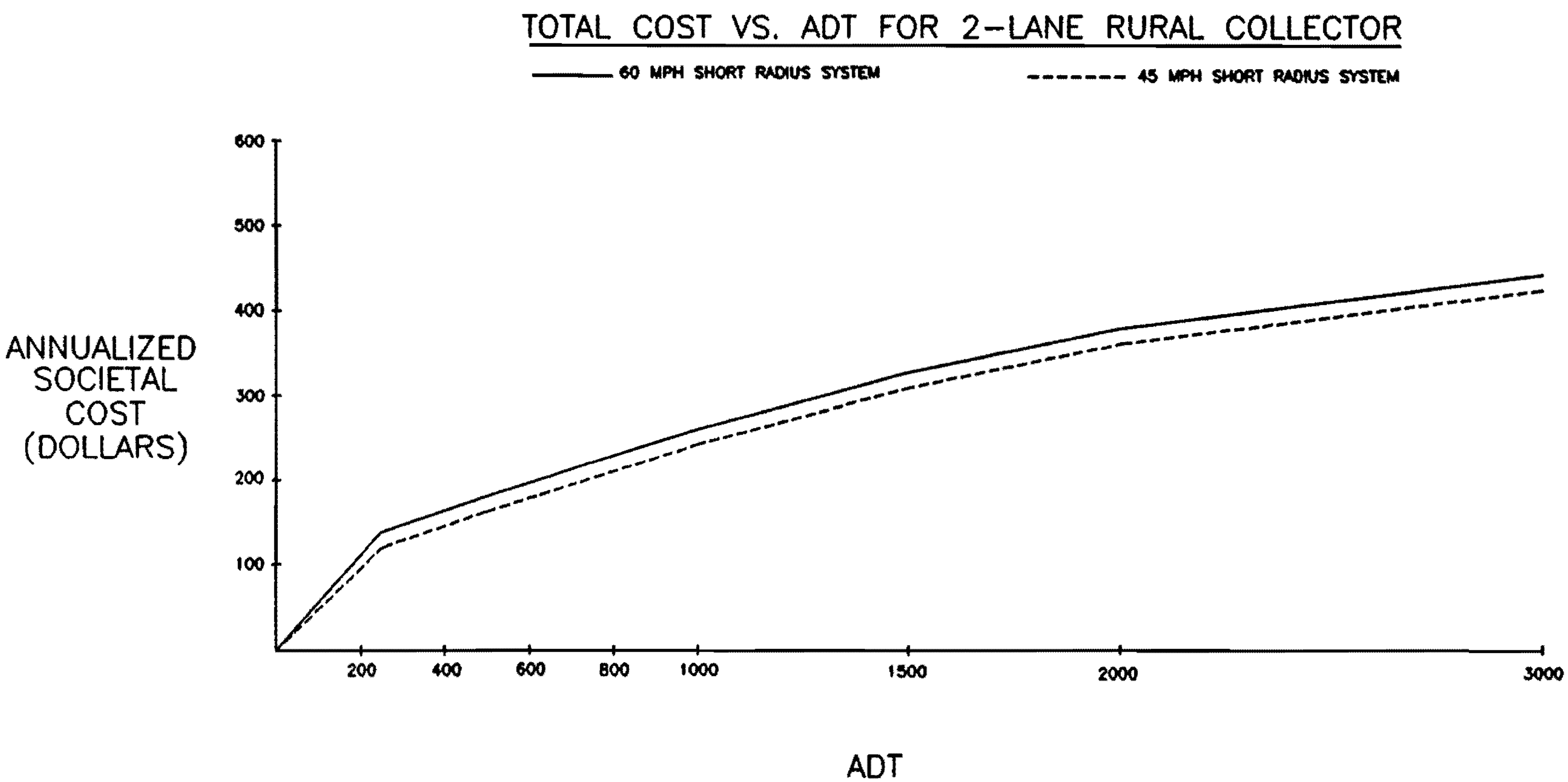


FIGURE C-1. Total Cost vs. ADT for the Short Radius Systems (2-Lane Rural Collector)

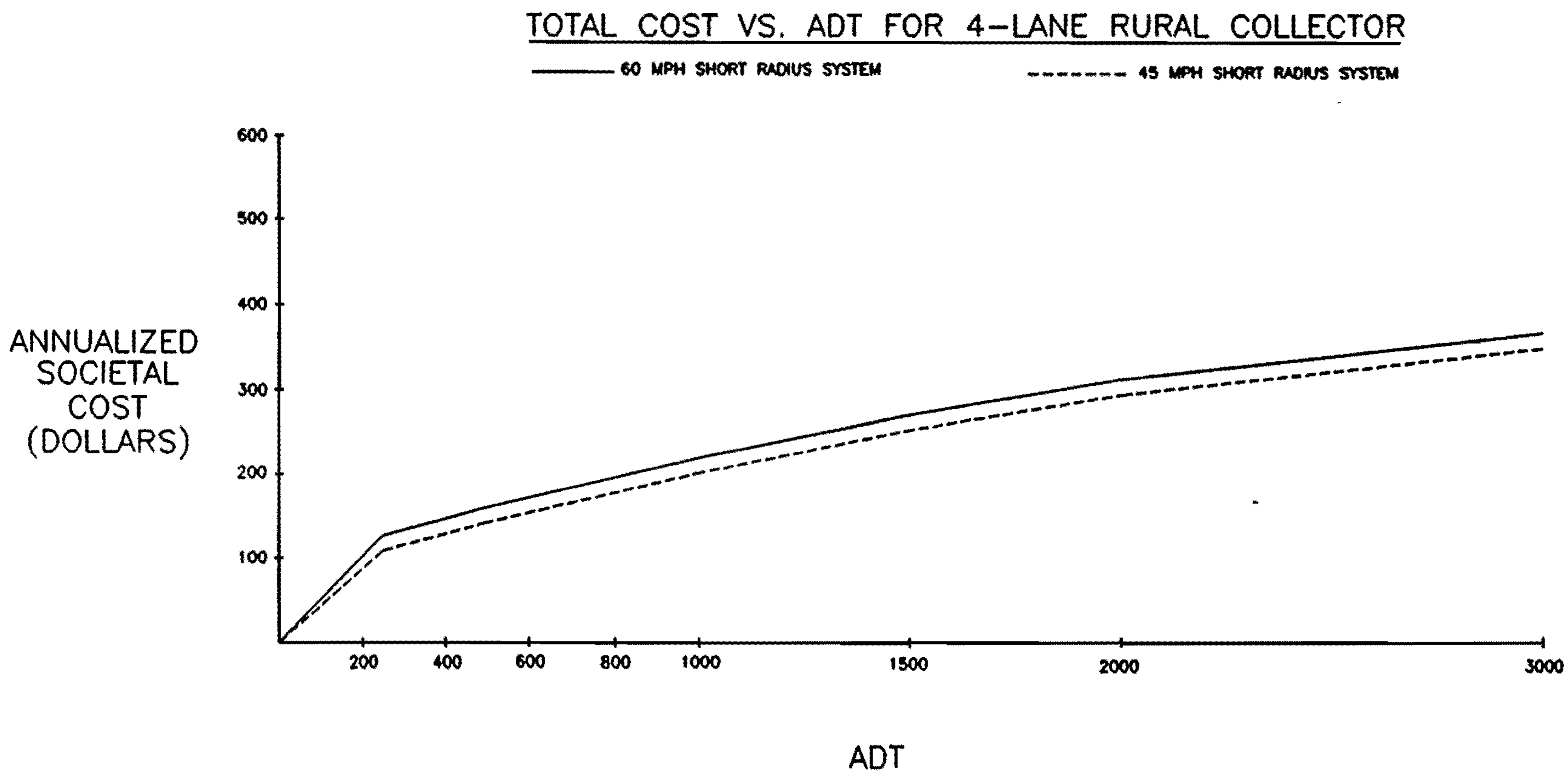


FIGURE C-2. Total Cost vs. ADT for the Short Radius Systems (4-Lane Rural Collector)

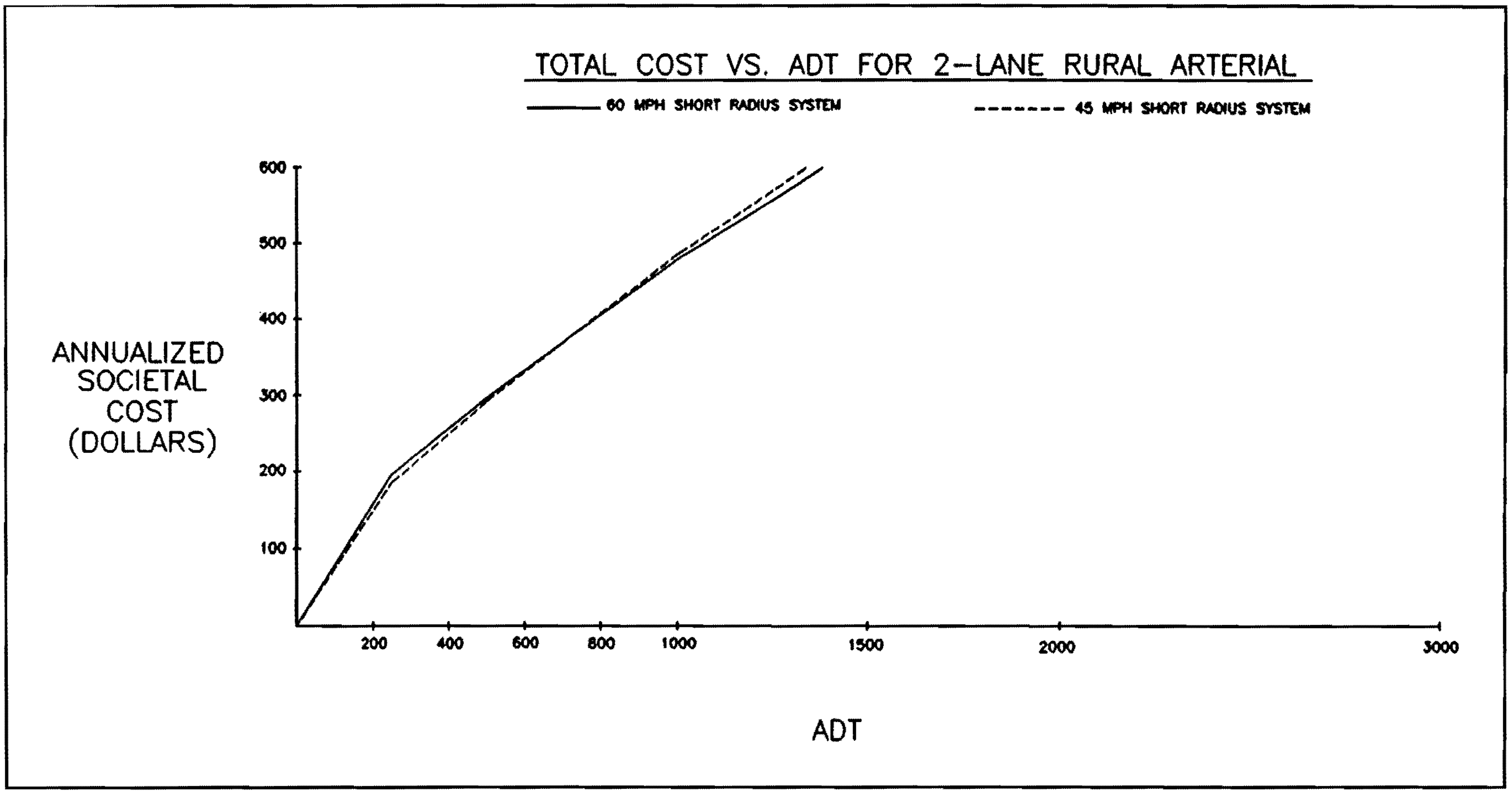


FIGURE C-3. Total Cost vs. ADT for the Short Radius Systems (2-Lane Rural Arterial)

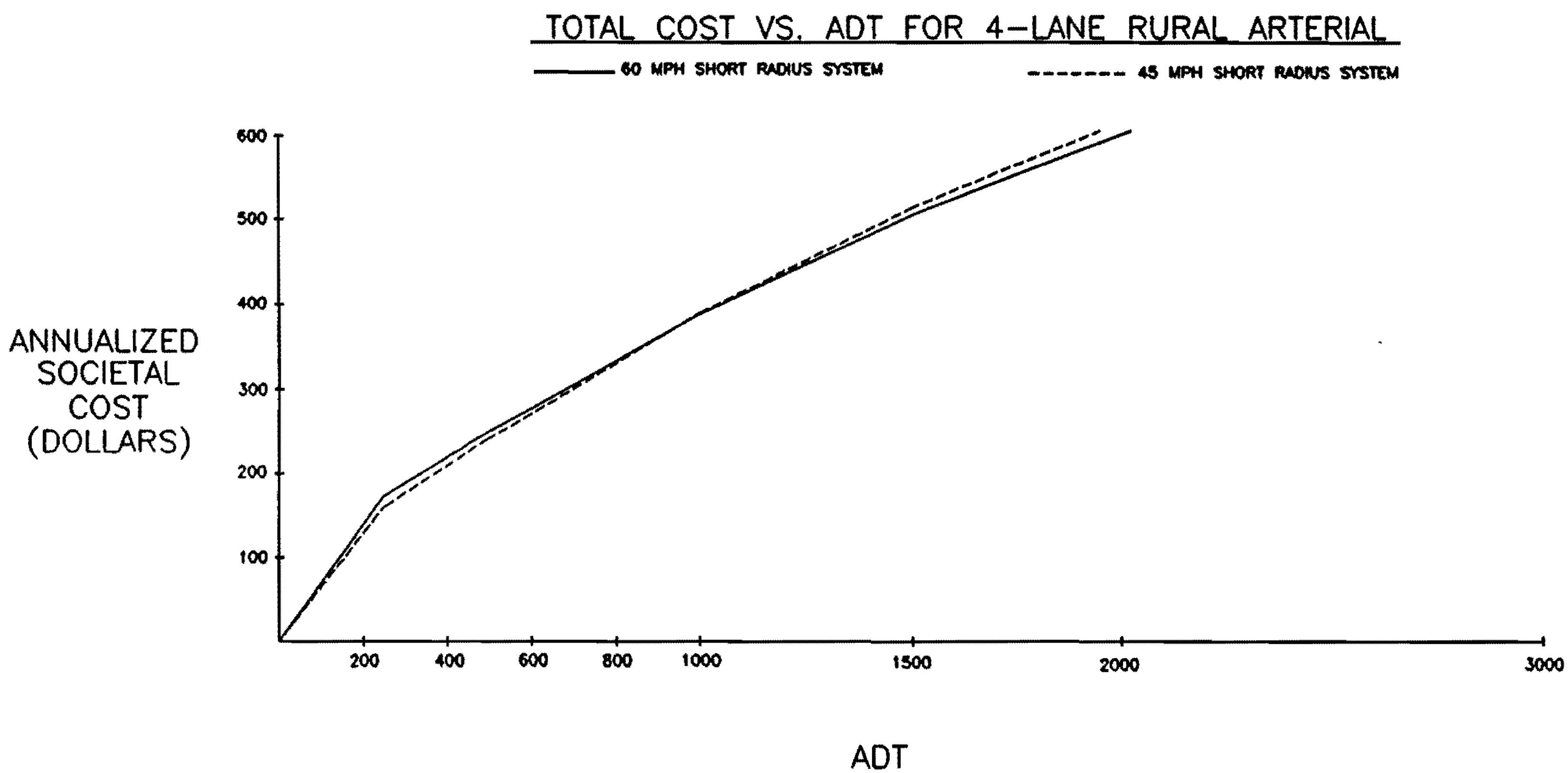


FIGURE C-4. Total Cost vs. ADT for the Short Radius Systems (4-Lane Rural Arterial)

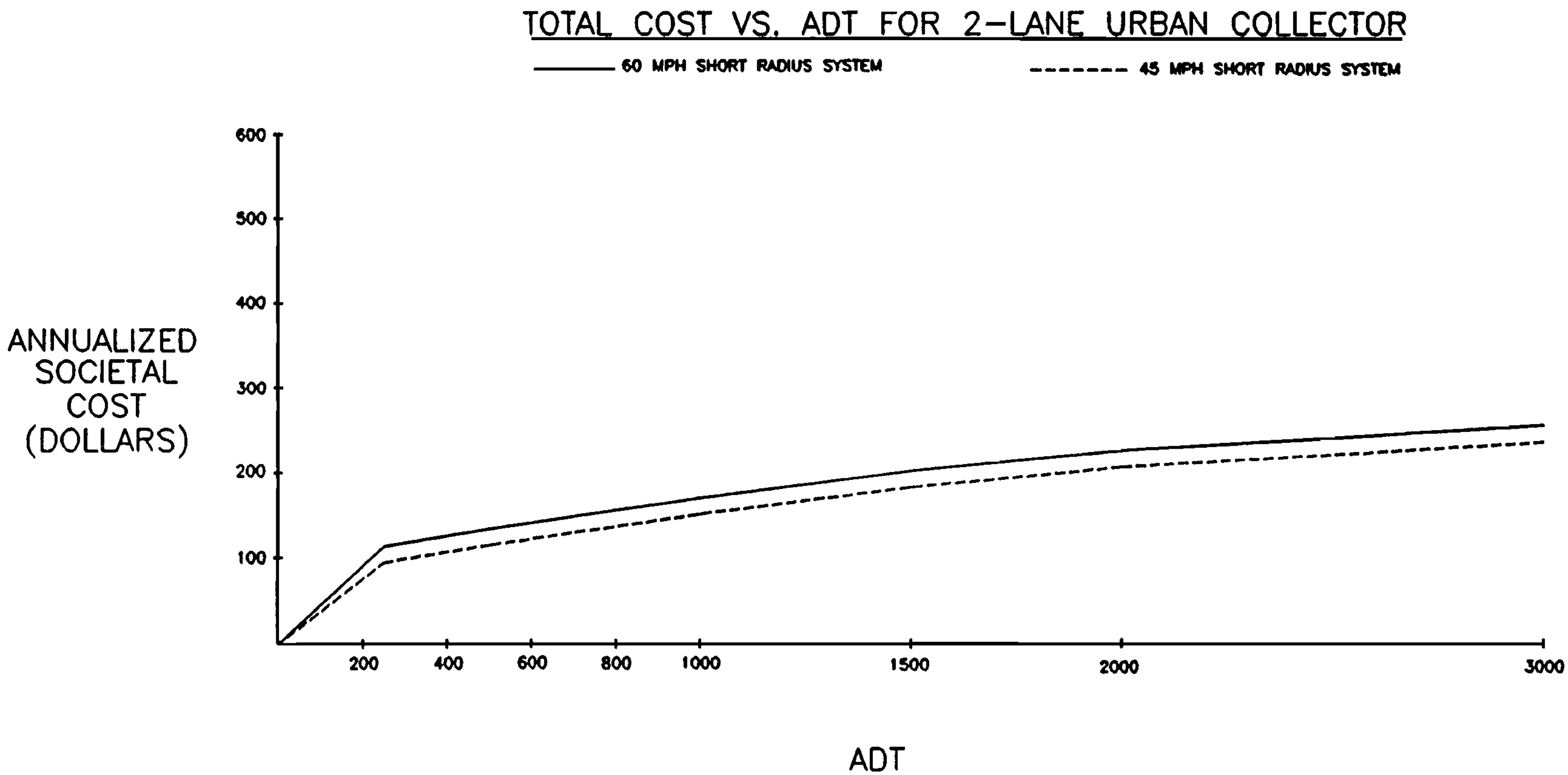


FIGURE C-5. Total Cost vs. ADT for the Short Radius Systems (2-Lane Urban Collector)

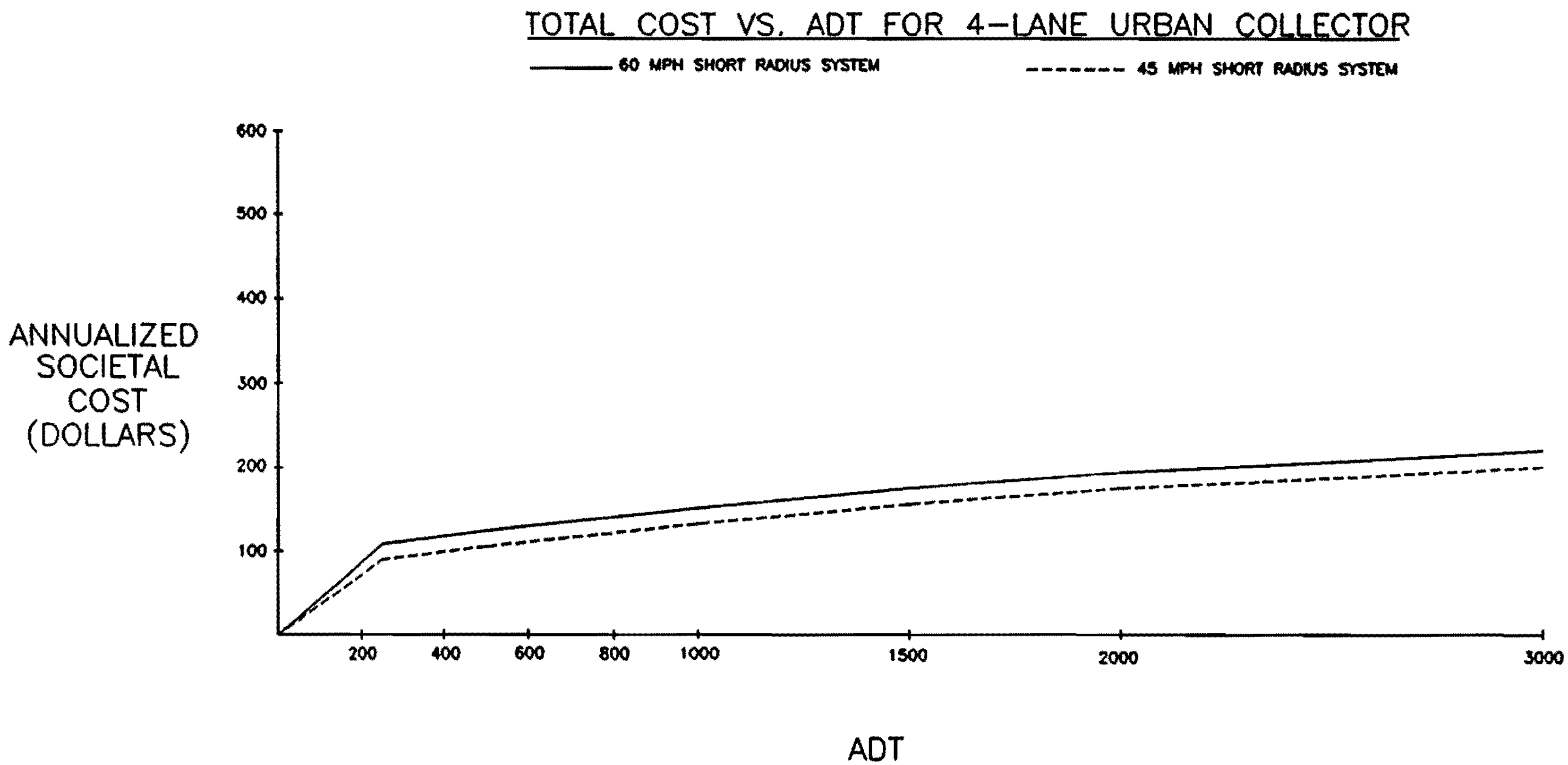


FIGURE C-6. Total Cost vs. ADT for the Short Radius Systems (4-Lane Urban Collector)

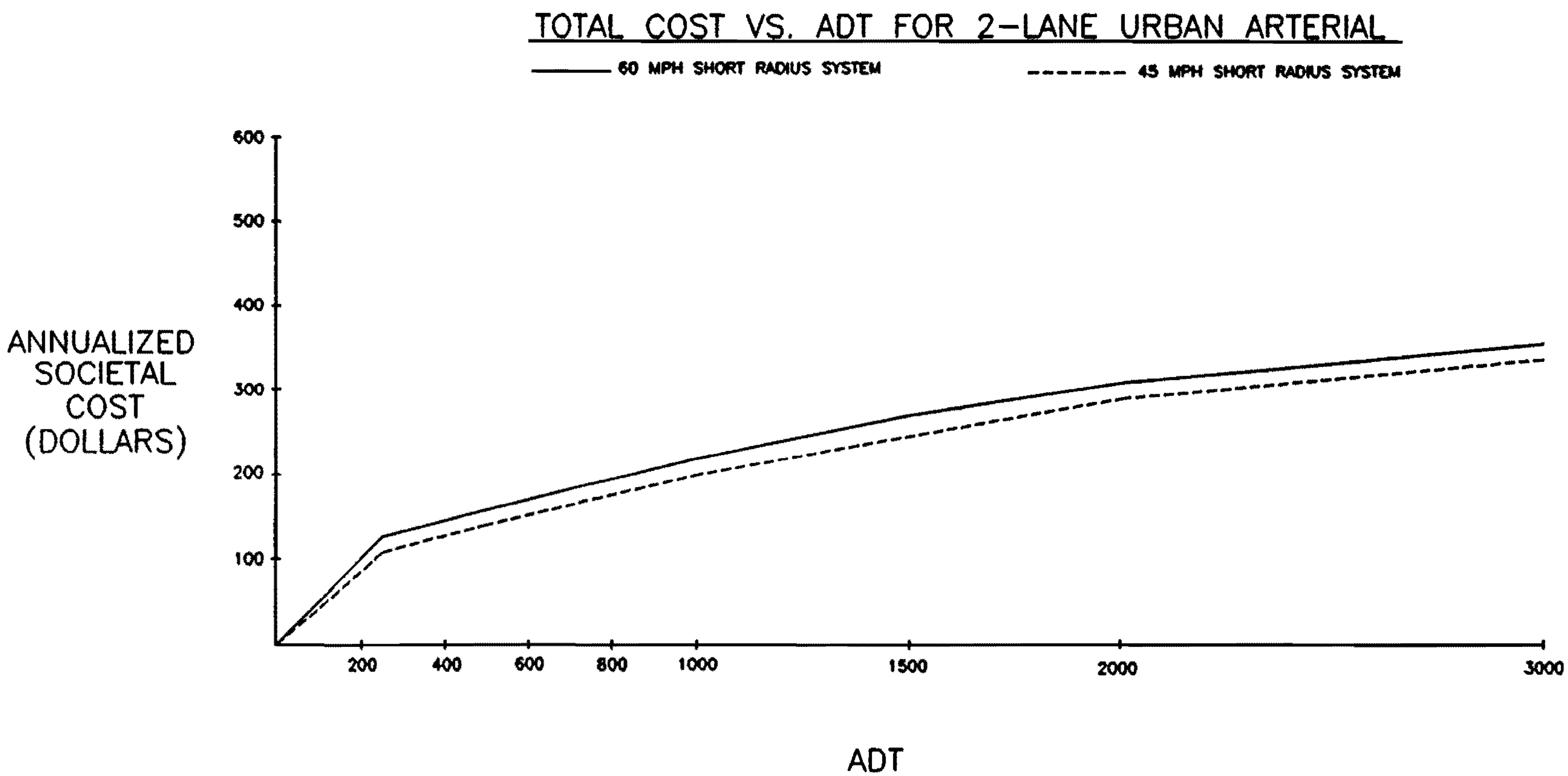


FIGURE C-7. Total Cost vs. ADT for the Short Radius Systems (2-Lane Urban Arterial)

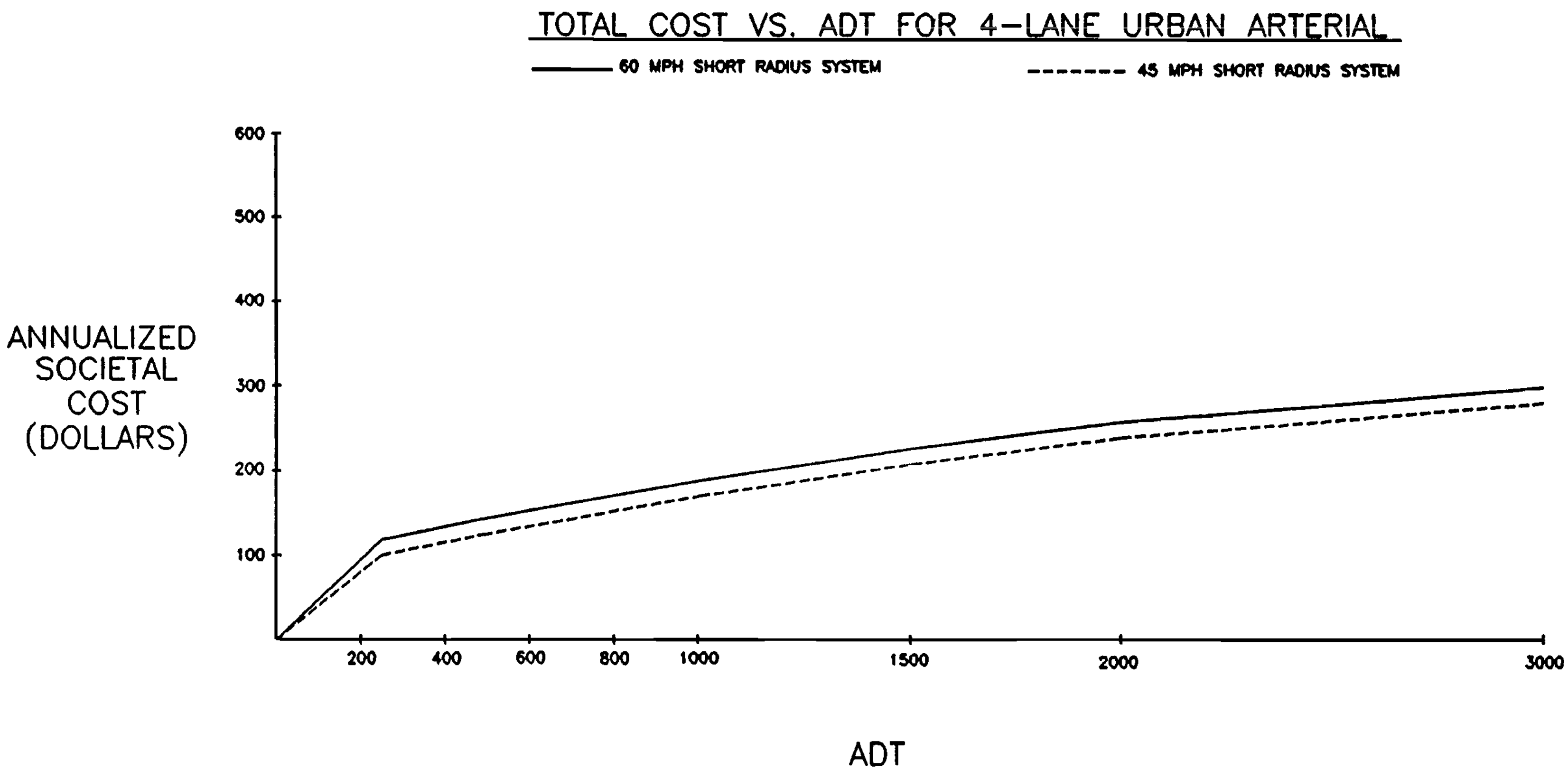


FIGURE C-8. Total Cost Vs. ADT for the Short Radius Systems (4-Lane Urban Arterial)

APPENDIX D

SURVEY PHOTOGRAPHS AND DIAGRAMS

APPENDIX D
SURVEY PHOTOGRAPHS AND DIAGRAMS

This appendix summarizes data gathered during site surveys made in the initial part of the study. These sites were in the Pharr/McAllen area of south Texas, within TxDOT District 21.

A diagram showing the geometry of each site is provided, along with selected photos of the site. With the exception of site 1, all sites were located on two-lane roadways of the rural collector, rural arterial, or urban arterial class.

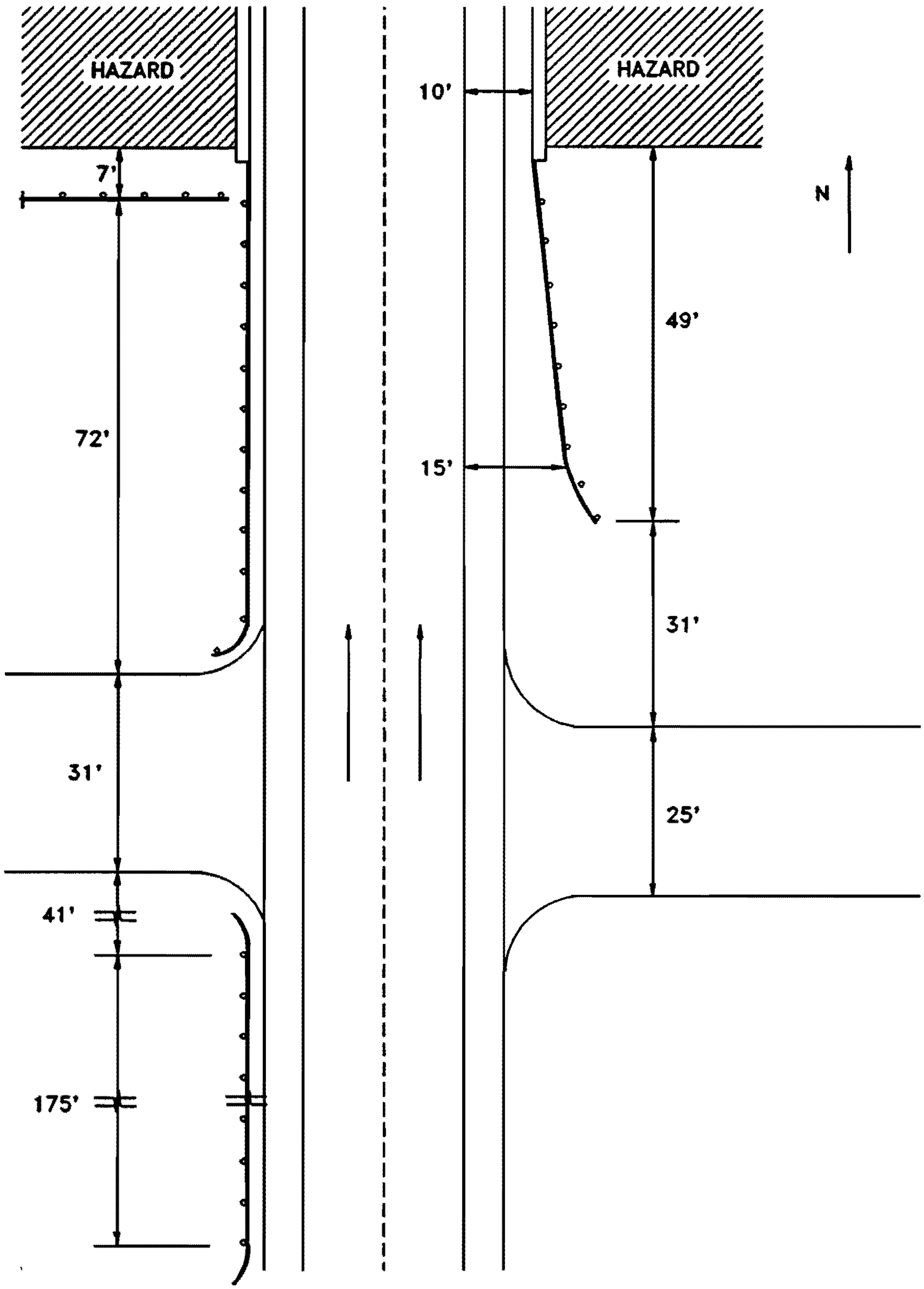
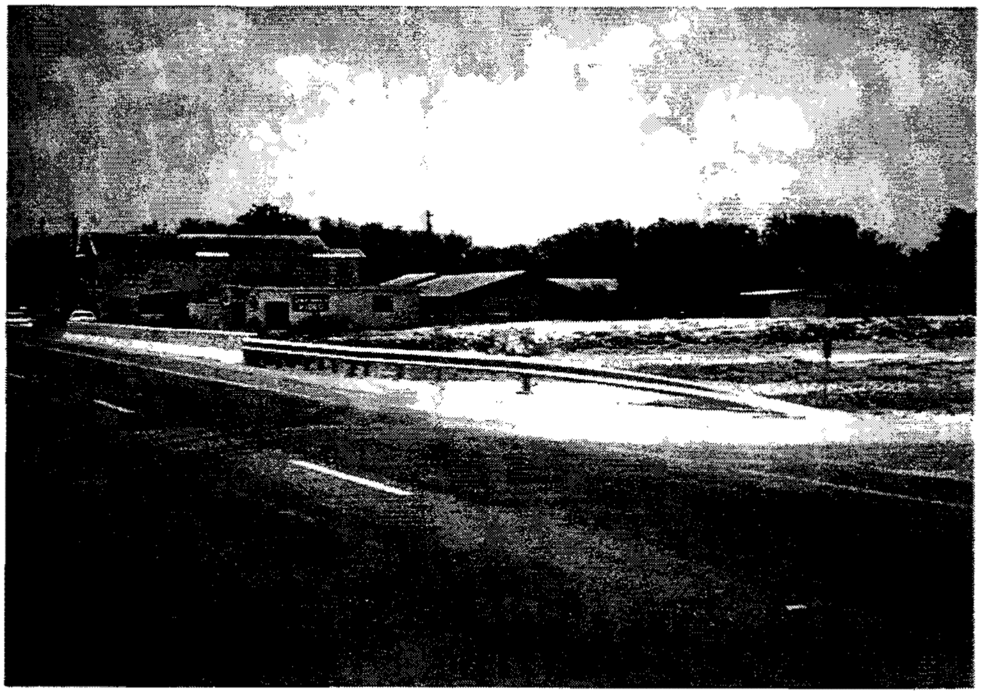


FIGURE D-1. Diagram of Site 1 (4-Lane, Rural Arterial)



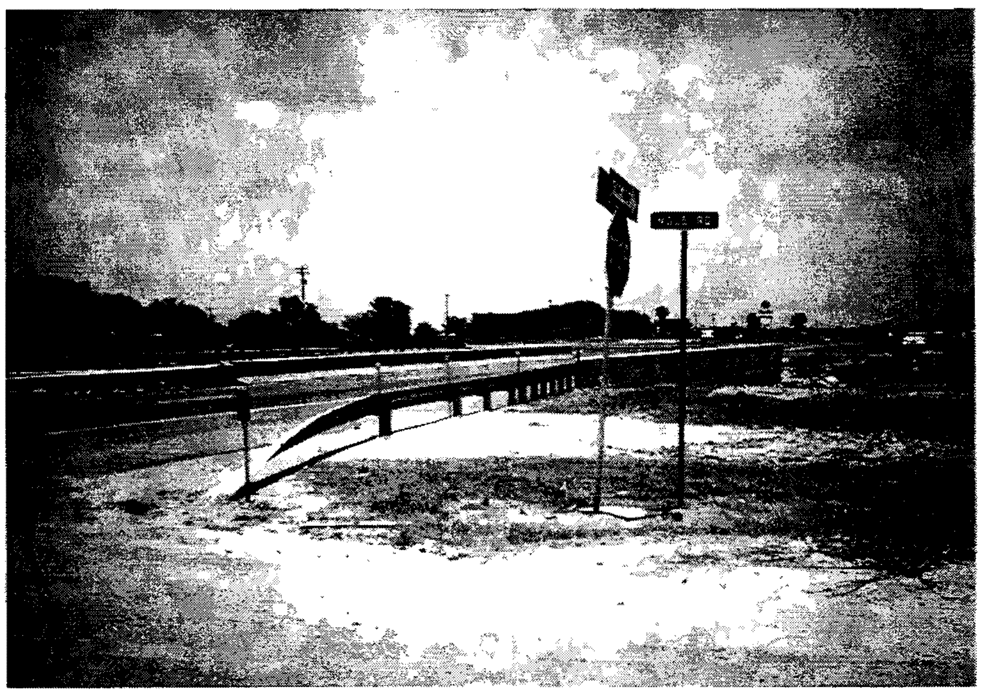


FIGURE D-2. Photographs of Site 1

FIGURE D-2. Photographs of Site 1 (continued)

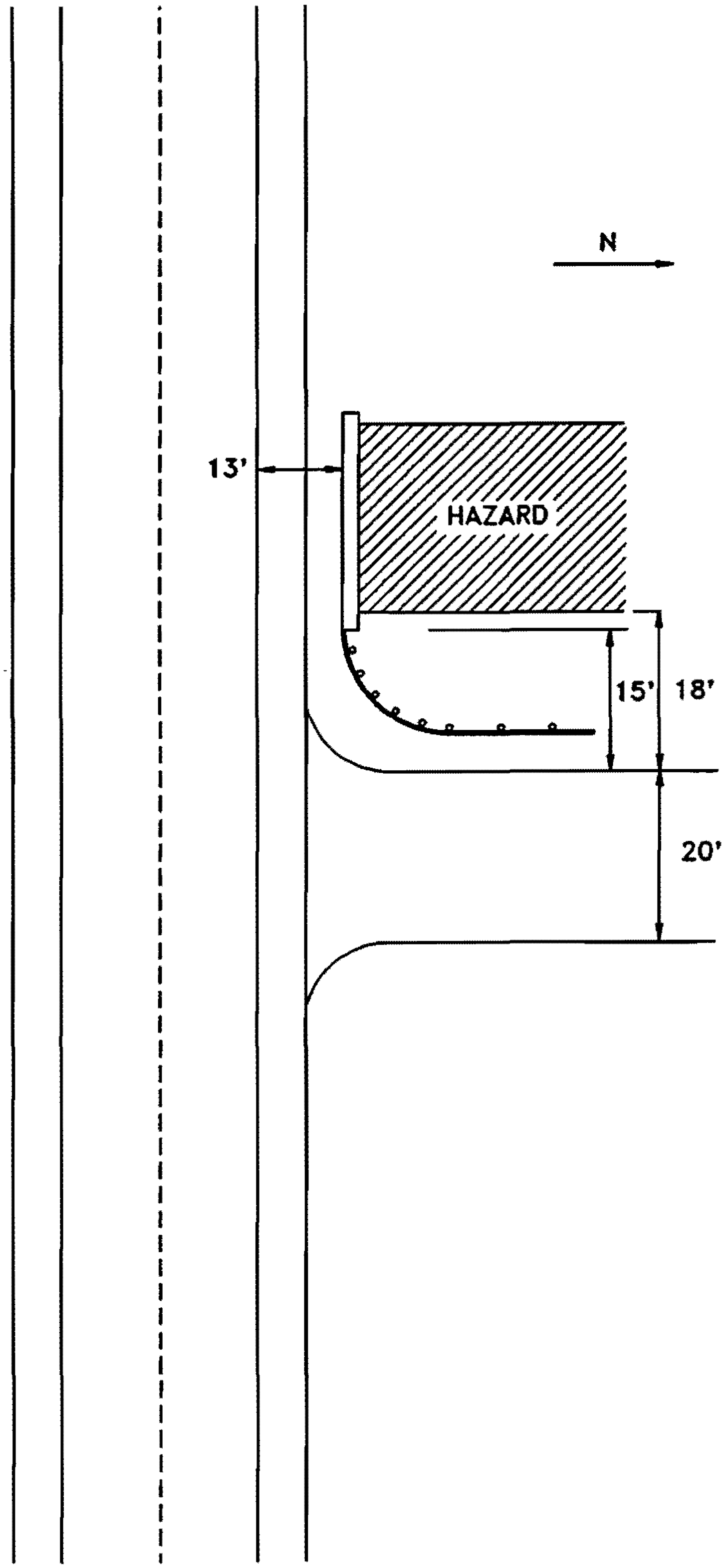
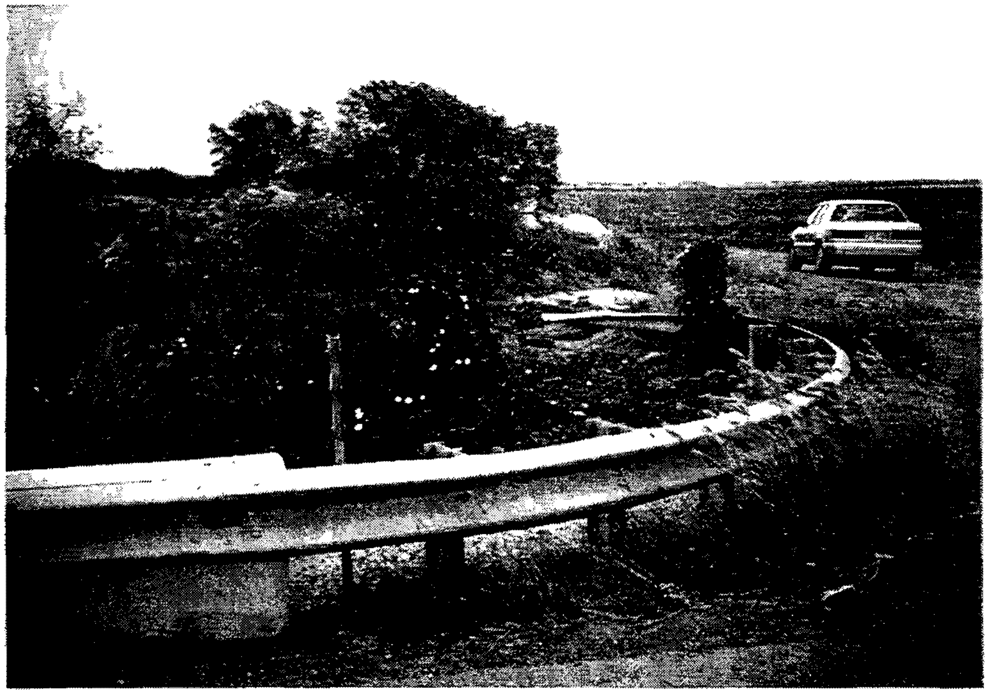


FIGURE D-3. Diagram of Site 2 (2-Lane Rural Collector)



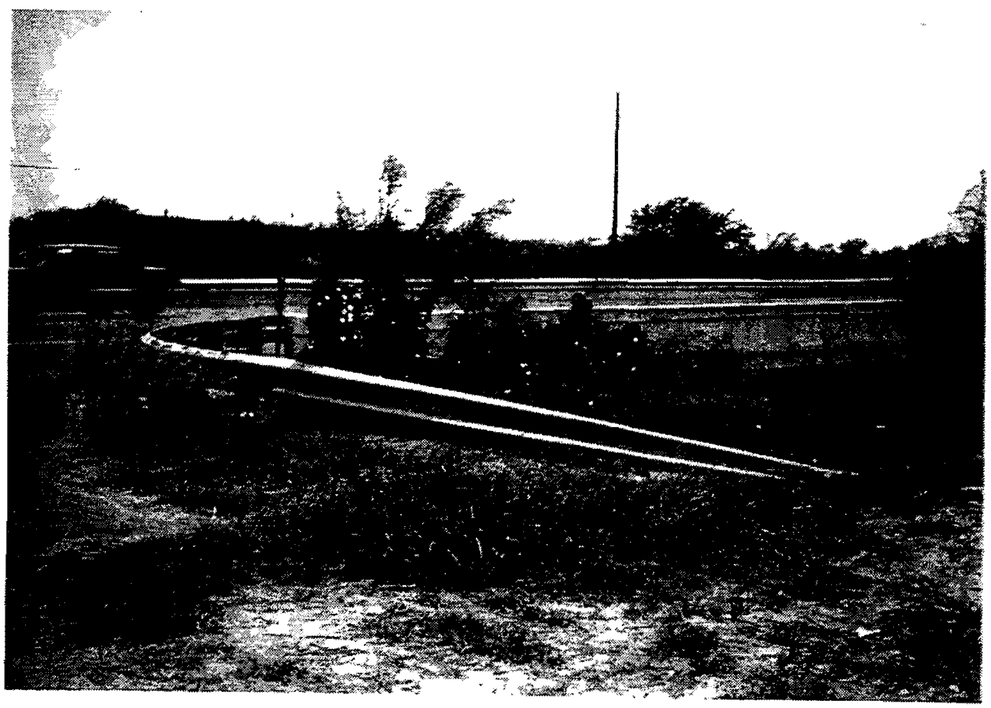
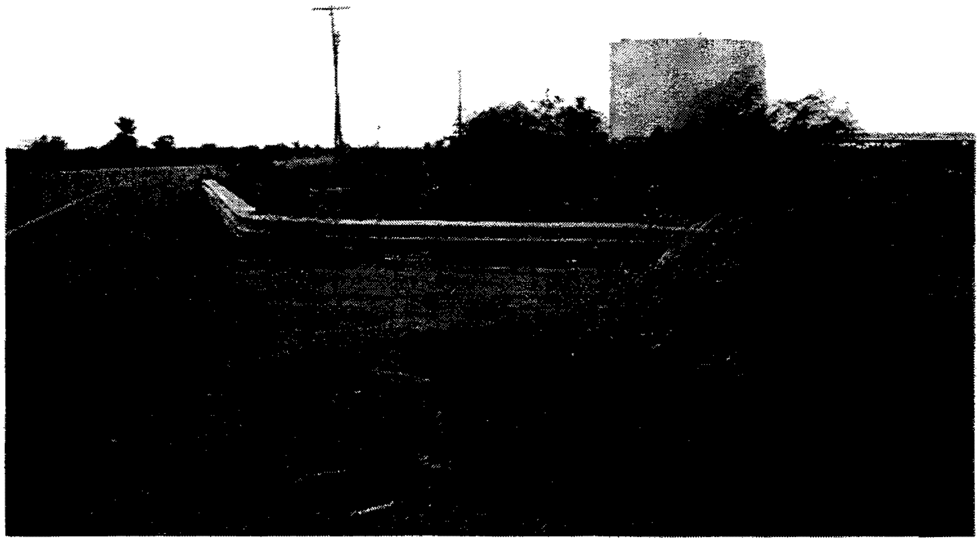


FIGURE D-4. Photographs of Site 2



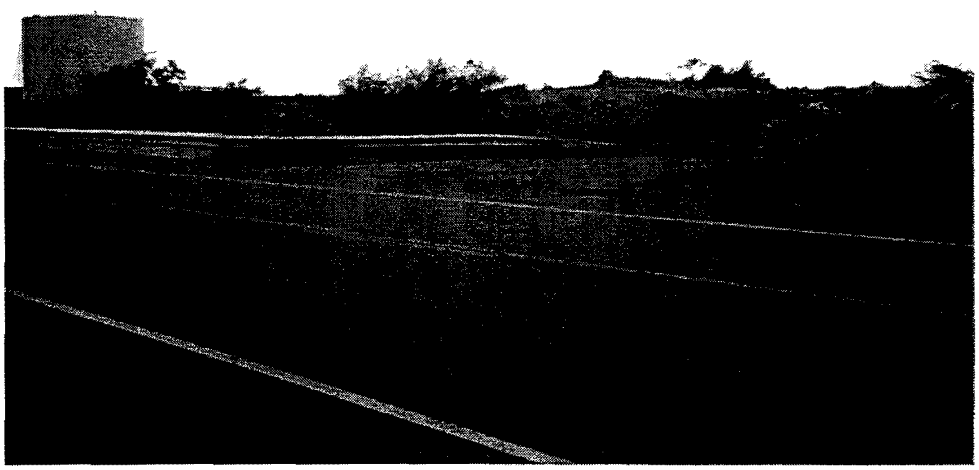


FIGURE D-4. Photographs of Site 2 (continued)

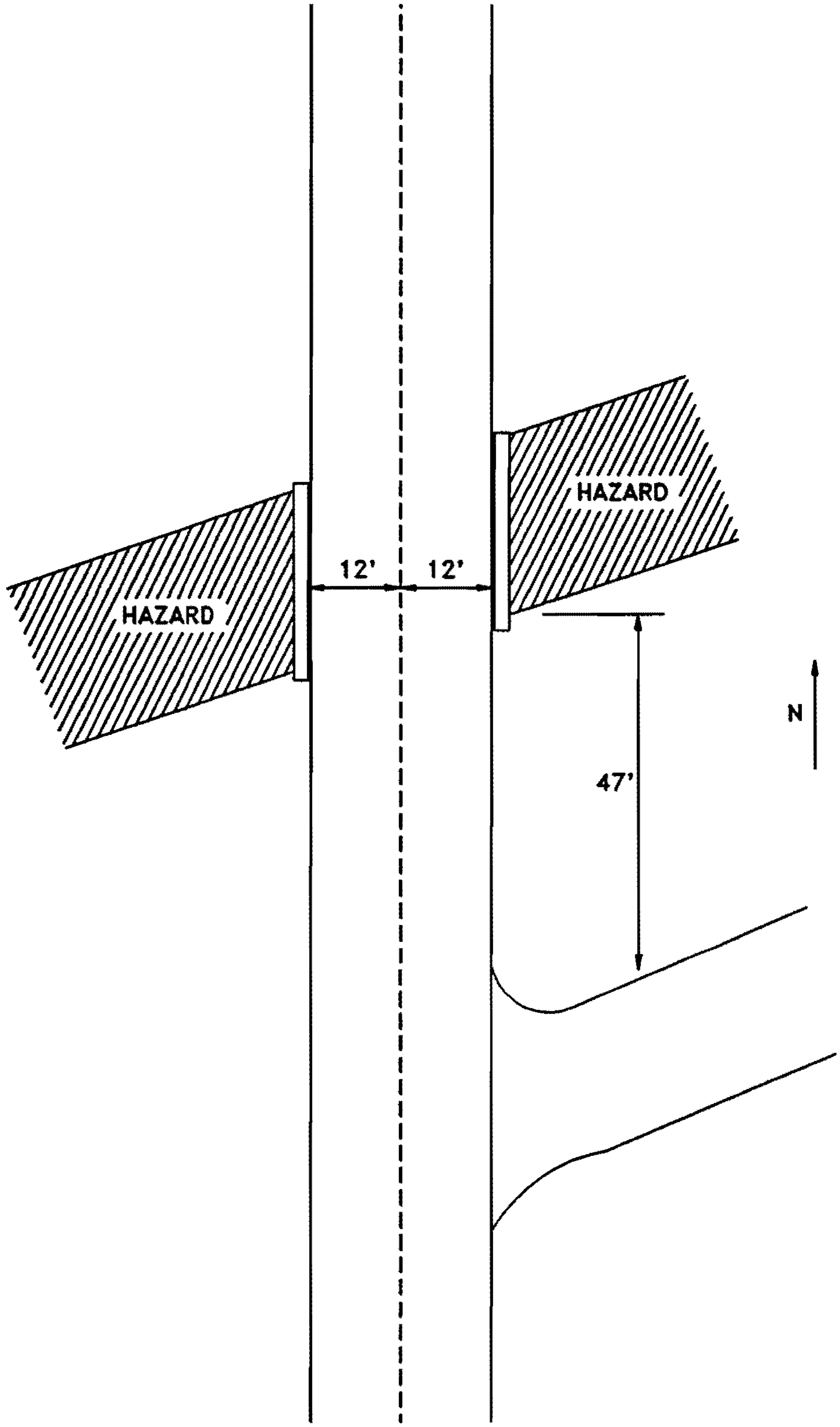


FIGURE D-5. Diagram of Site 3 (2-Lane Rural Collector)

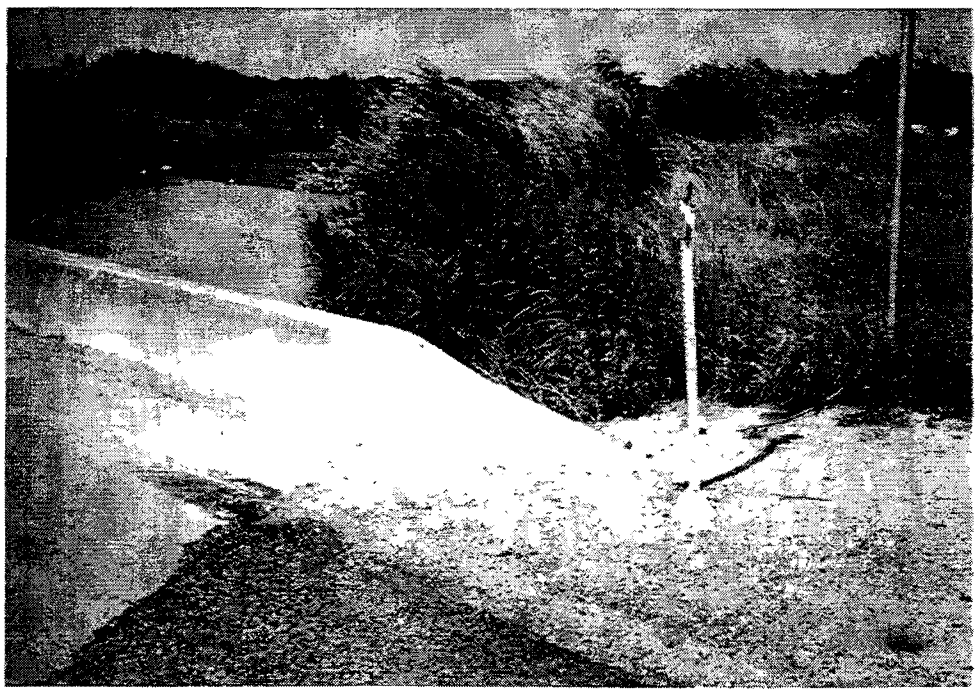


FIGURE D-6. Photographs of Site 3

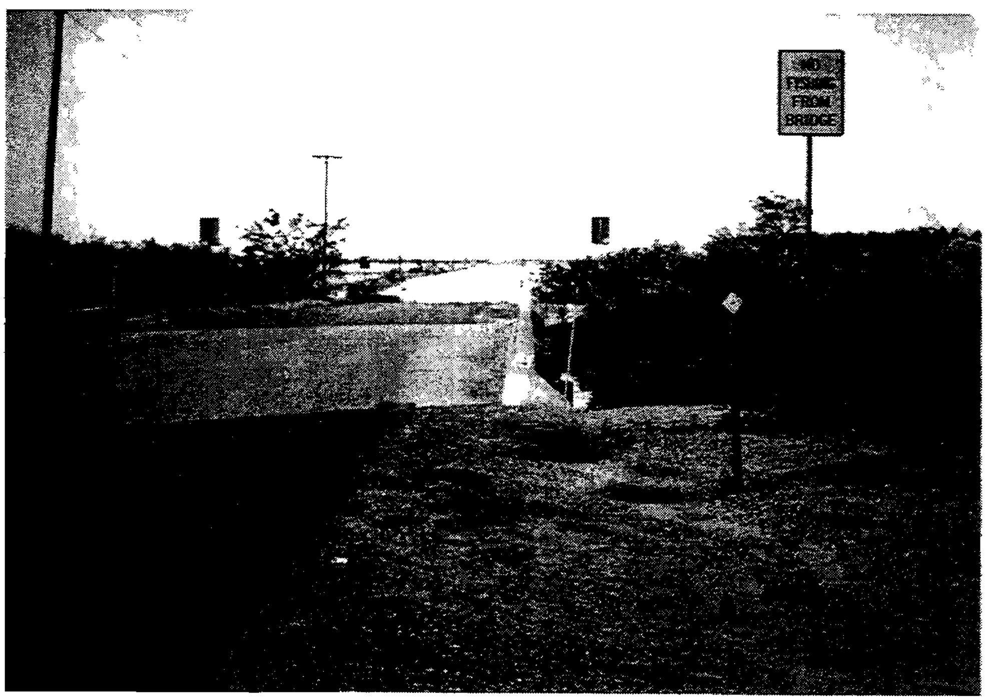


FIGURE D-6. Photographs of Site 3 (continued)

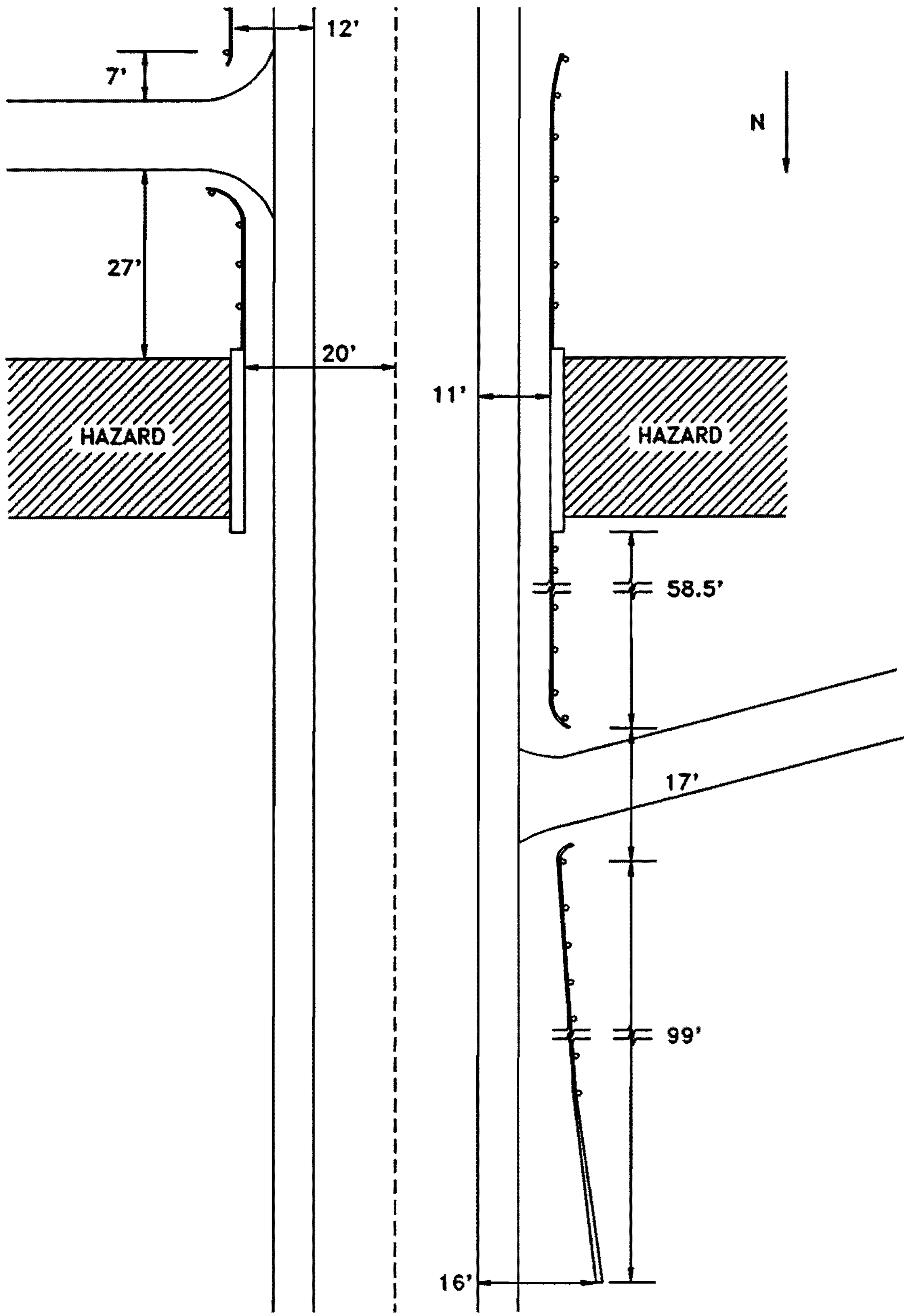


FIGURE D-7. Diagram of Site 4 (2-Lane Rural Collector)

FIGURE D-8. Photographs of Site 4

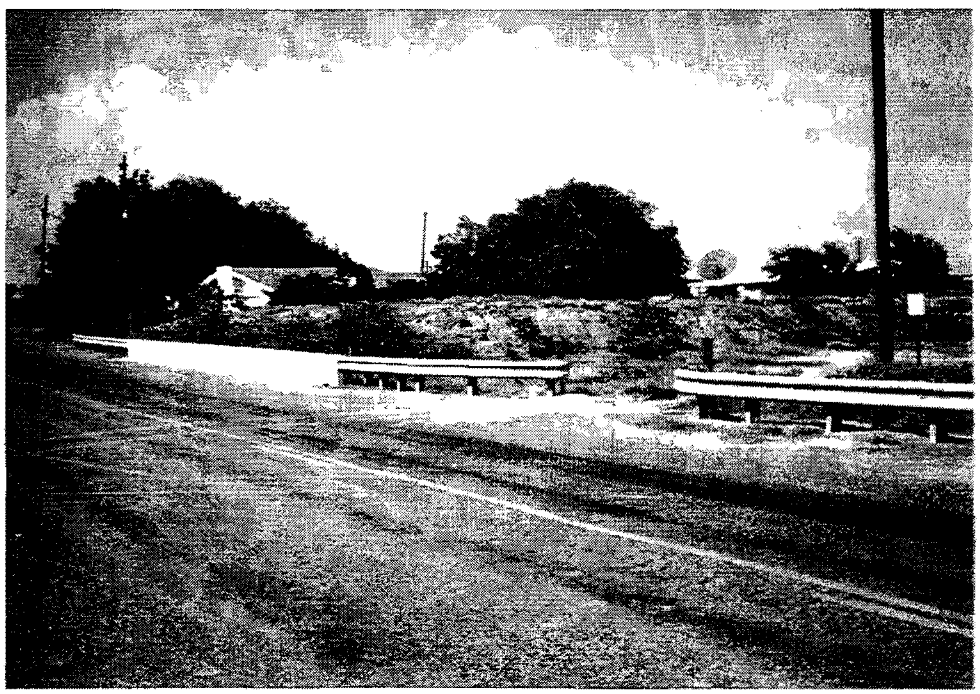


FIGURE D-8. Photographs of Site 4 (continued)

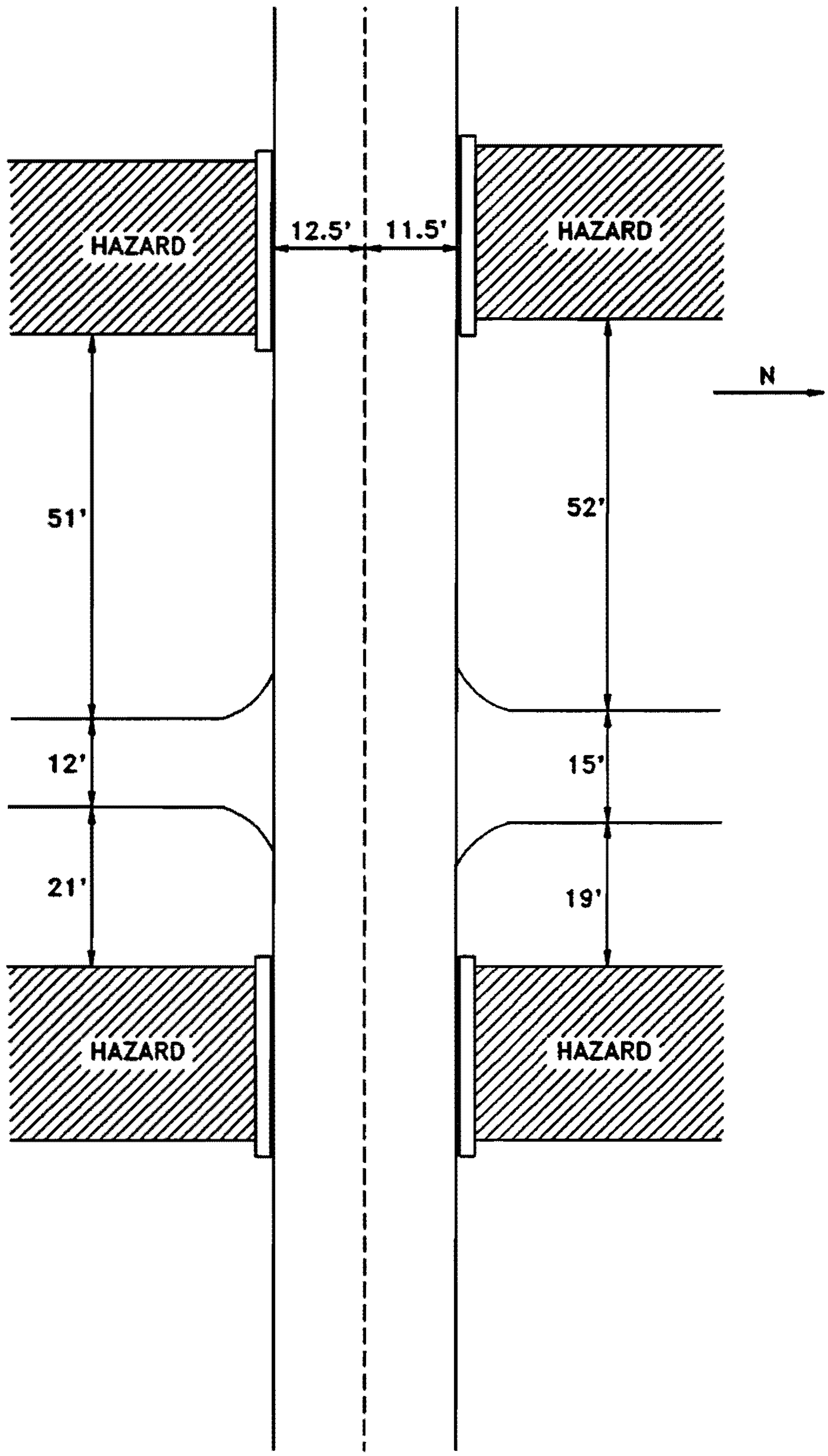


FIGURE D-9. Diagram of Site 5 (2-Lane Rural Collector)

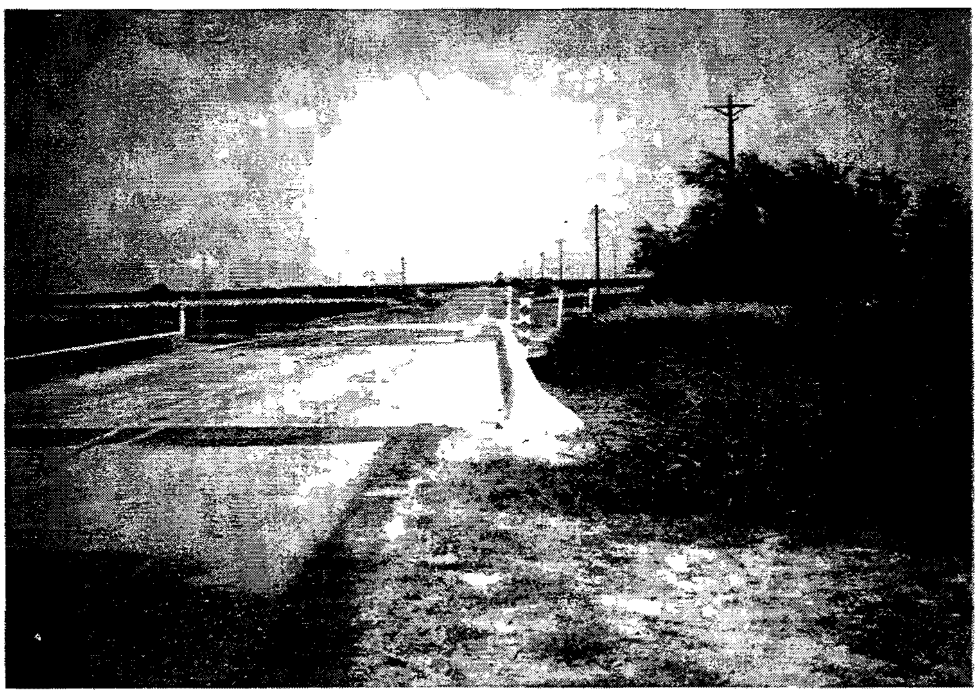


FIGURE D-10. Photographs of Site 5

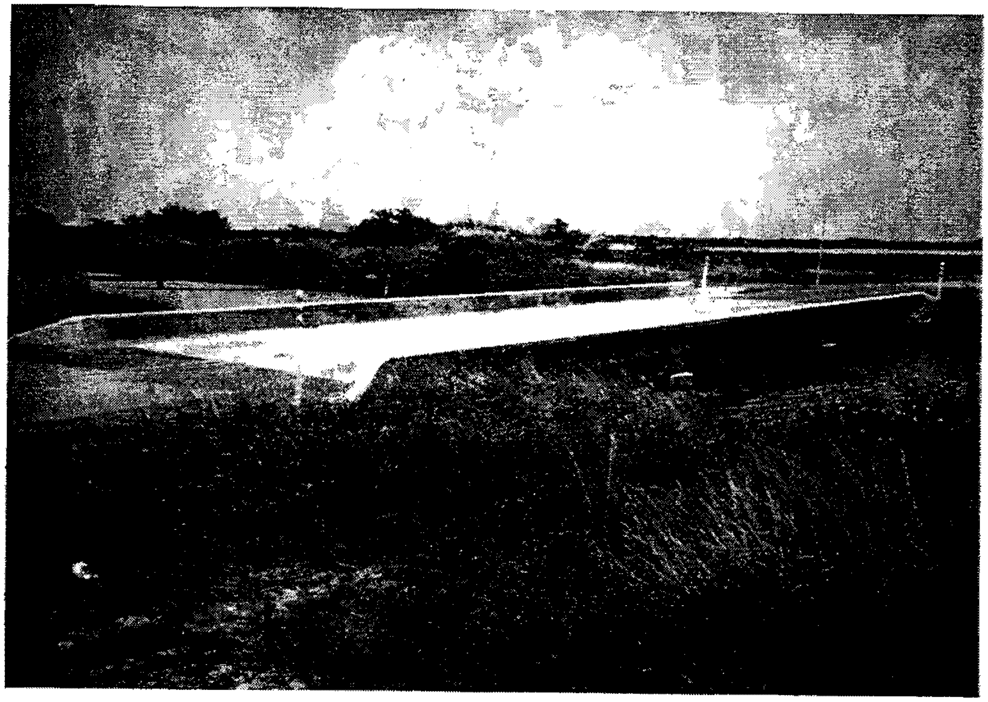


Figure D-10. Photographs of Site 5 (continued)

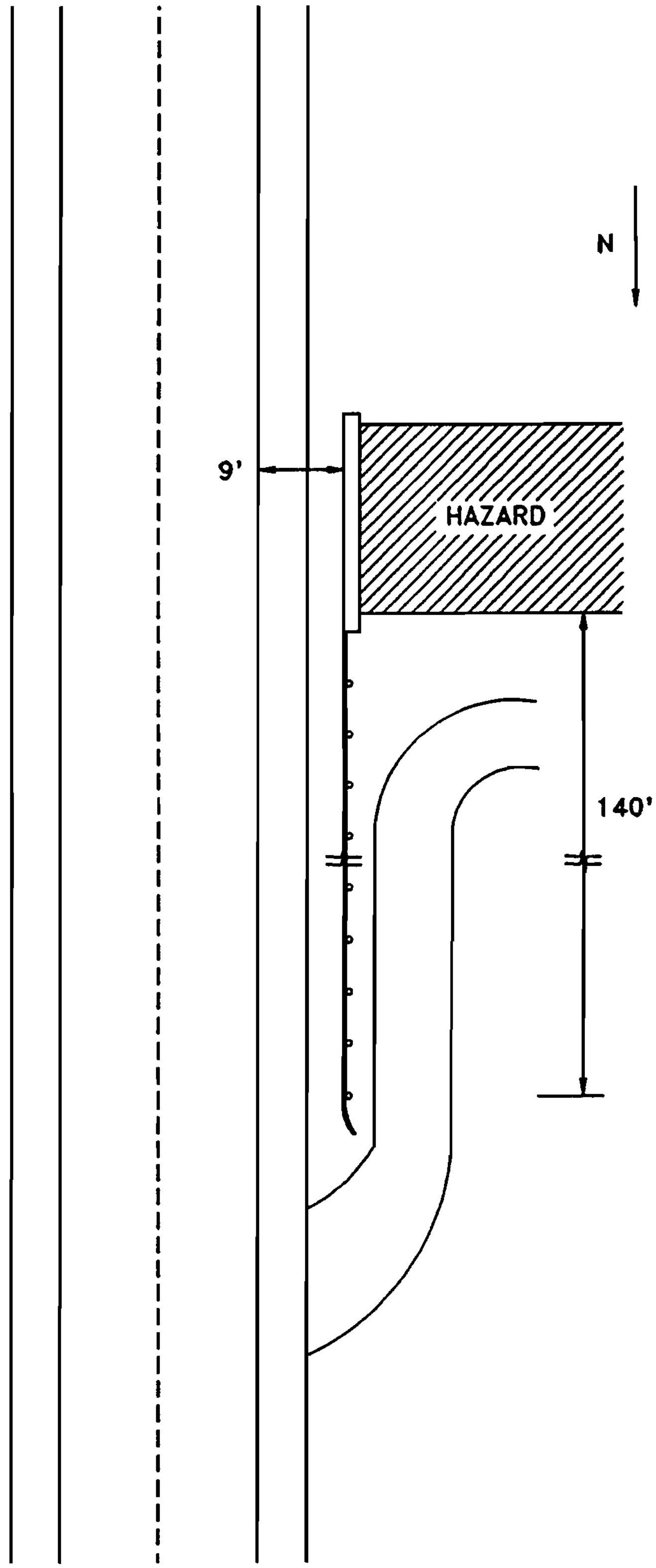


FIGURE D-11. Diagram of Site 6 (2-Lane Rural Arterial)

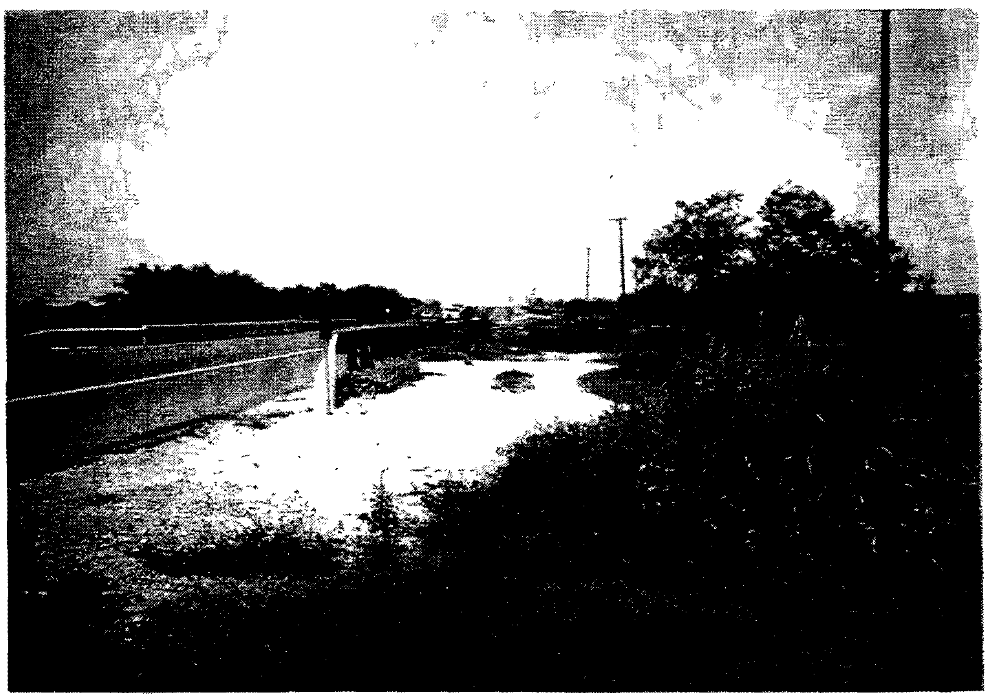


Figure D-12. Photographs of Site 6

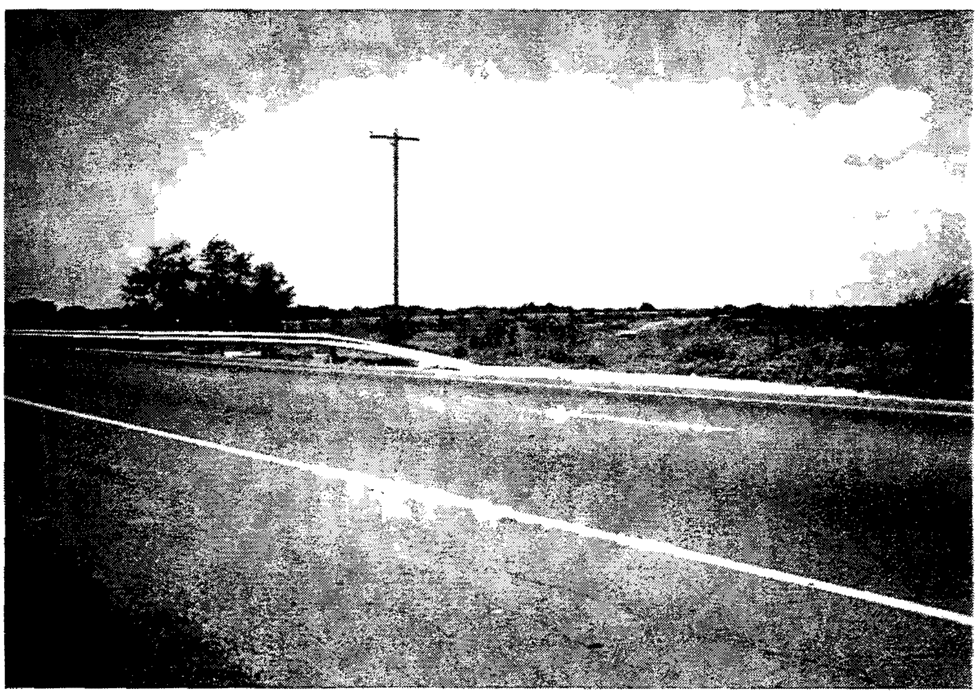


Figure D-12. Photographs of Site 6 (continued)

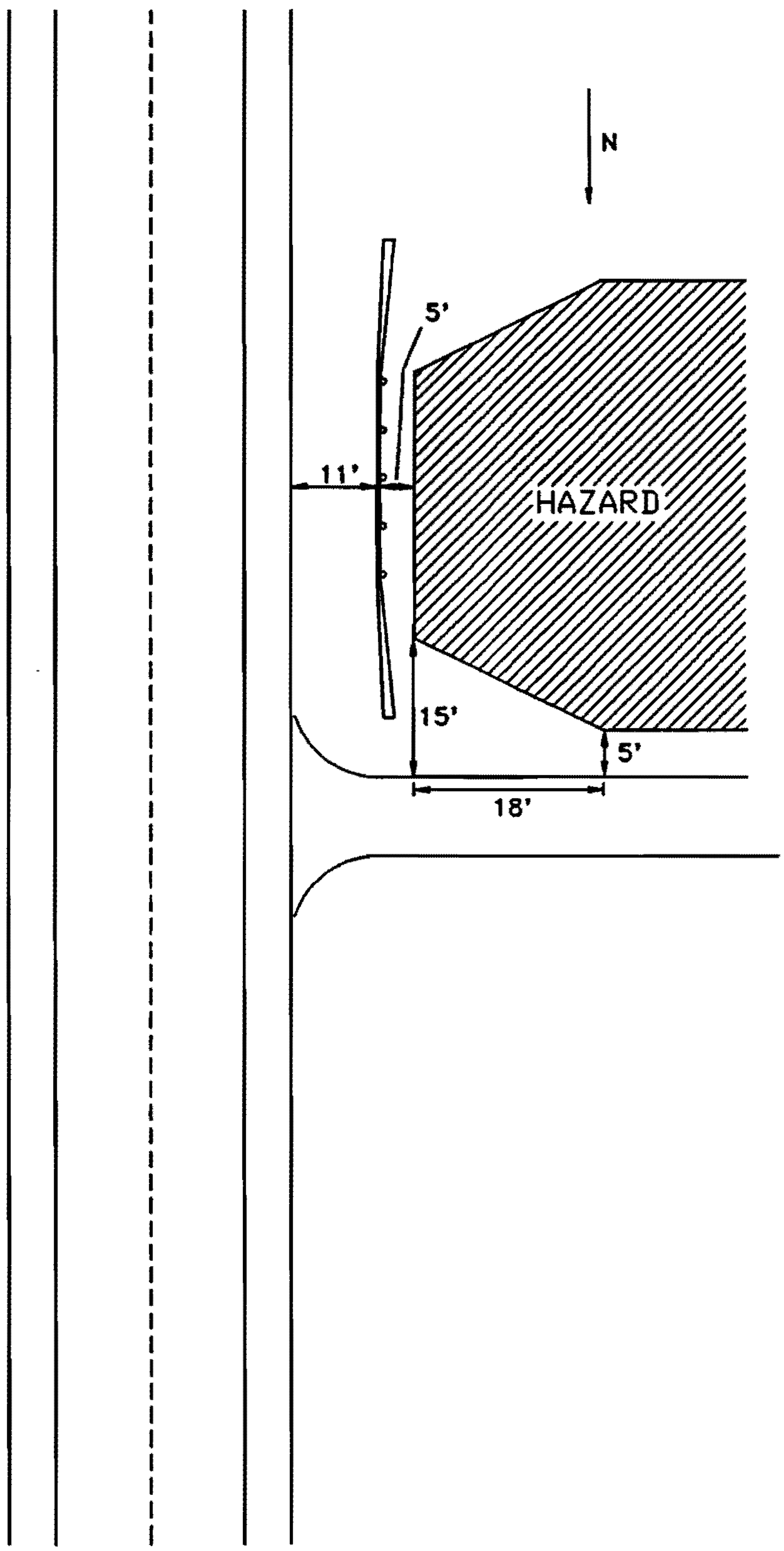


FIGURE D-13. Diagram of Site 7 (2-Lane Urban Arterial)

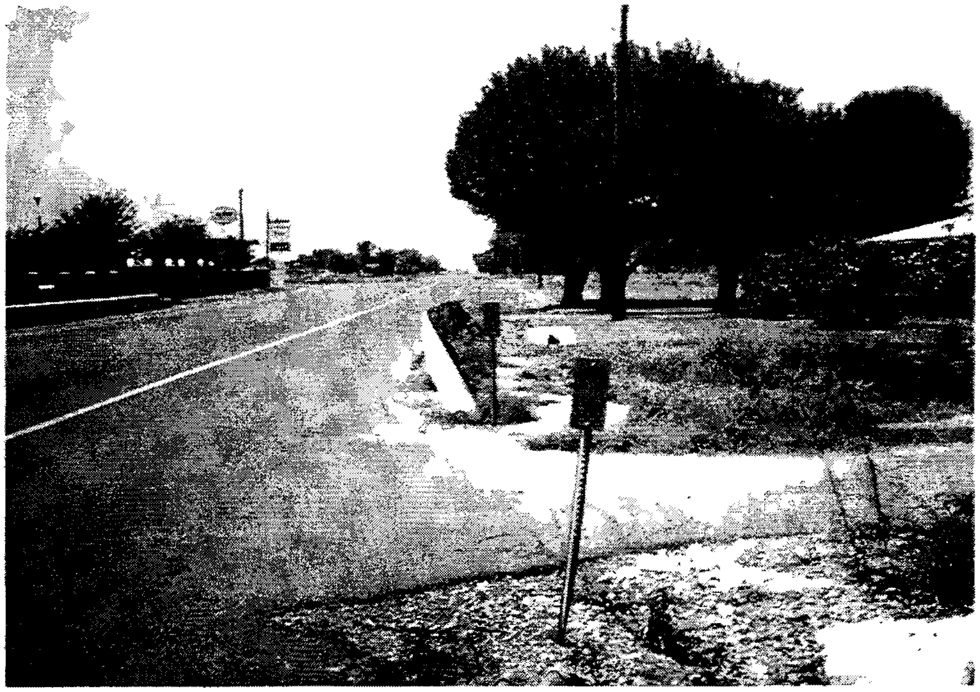


FIGURE D-14. Photographs of Site 7

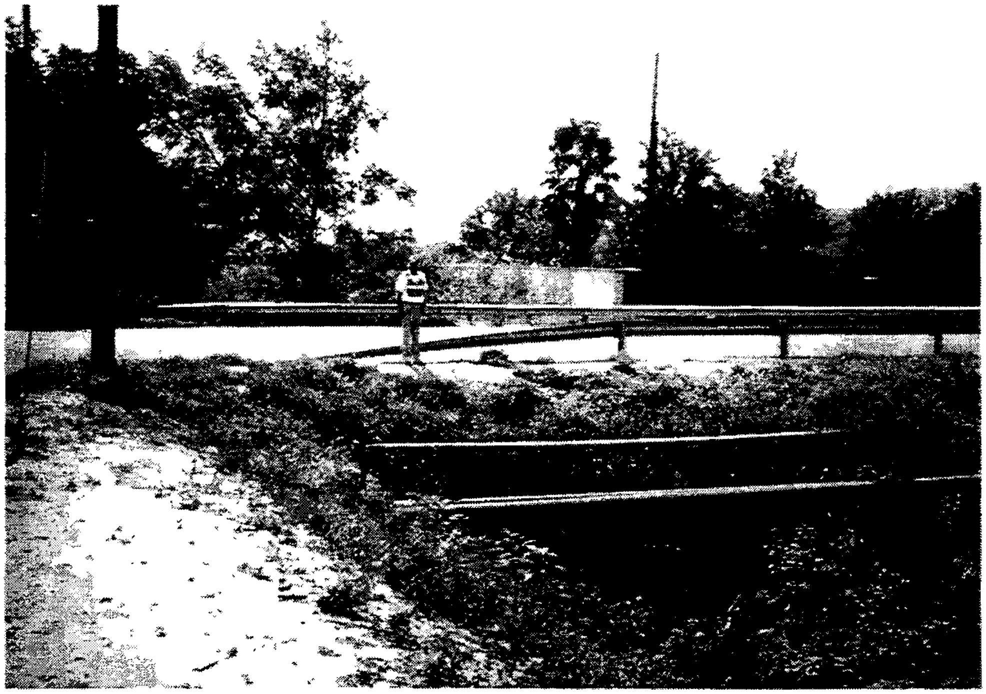


FIGURE D-14. Photographs of Site 7 (continued)

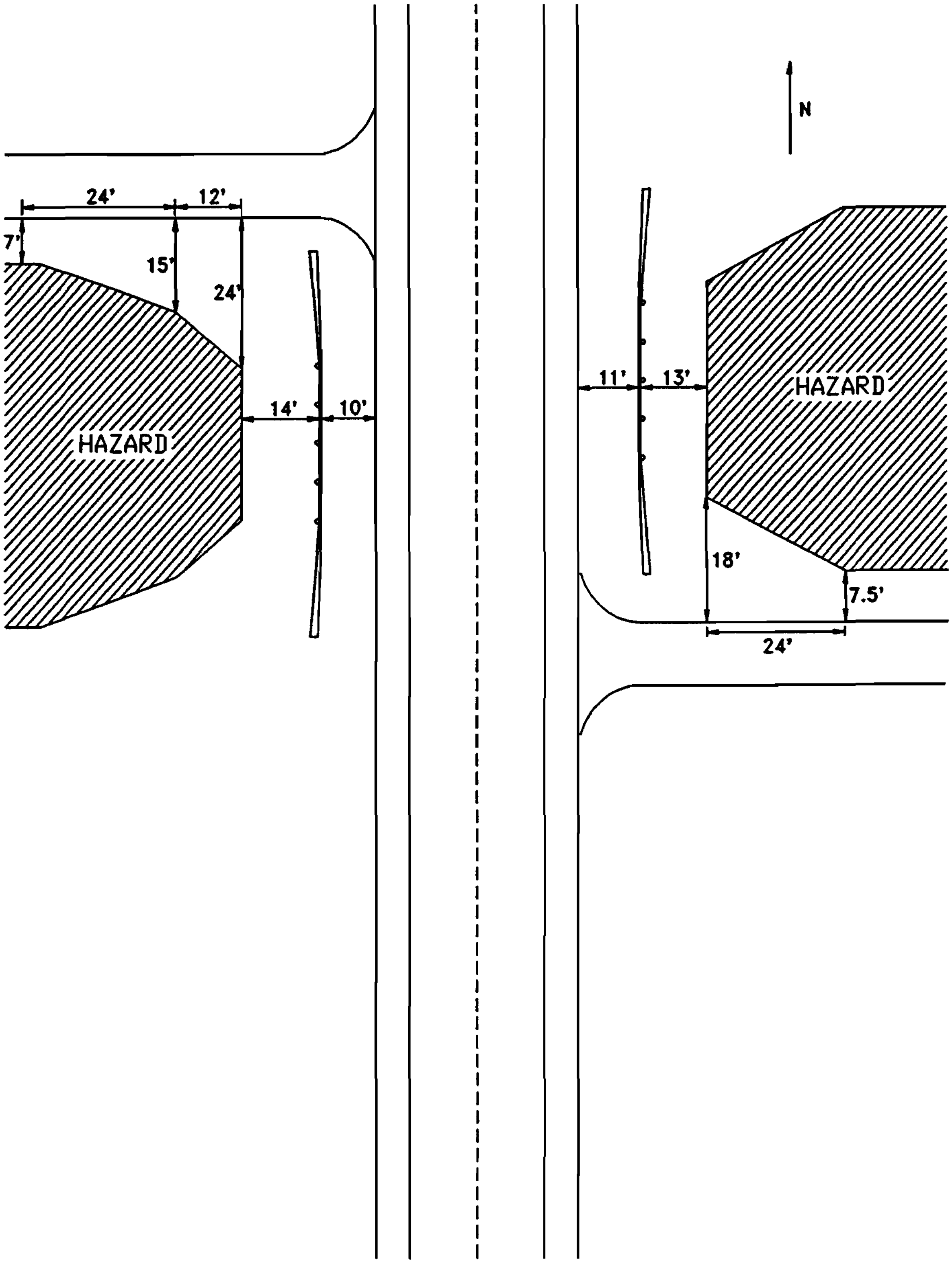


FIGURE D-15. Diagram of Site 8 (2-Lane Urban Arterial)

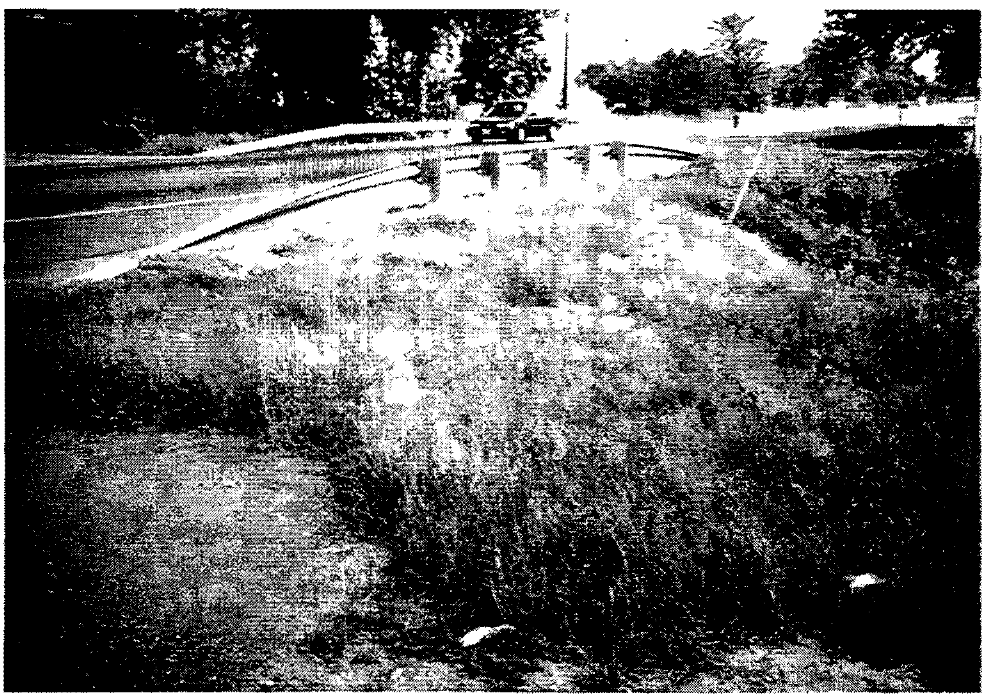


FIGURE D-16. Photographs of Site 8

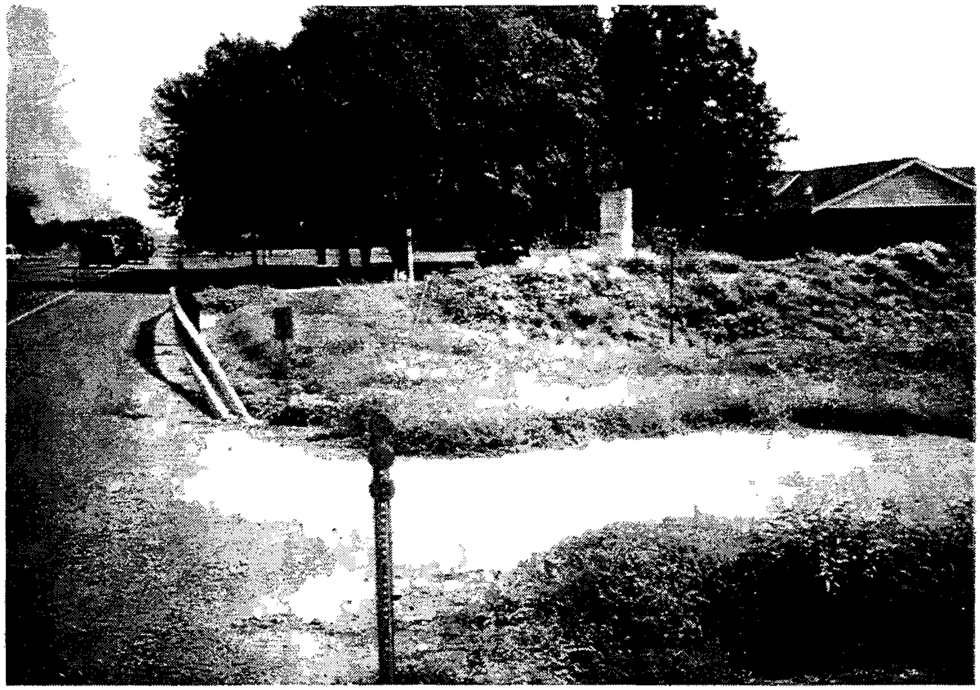


FIGURE D-16. Photographs of Site 8 (continued)

APPENDIX E

CONSTRUCTION DRAWINGS FOR AS-TESTED INSTALLATIONS

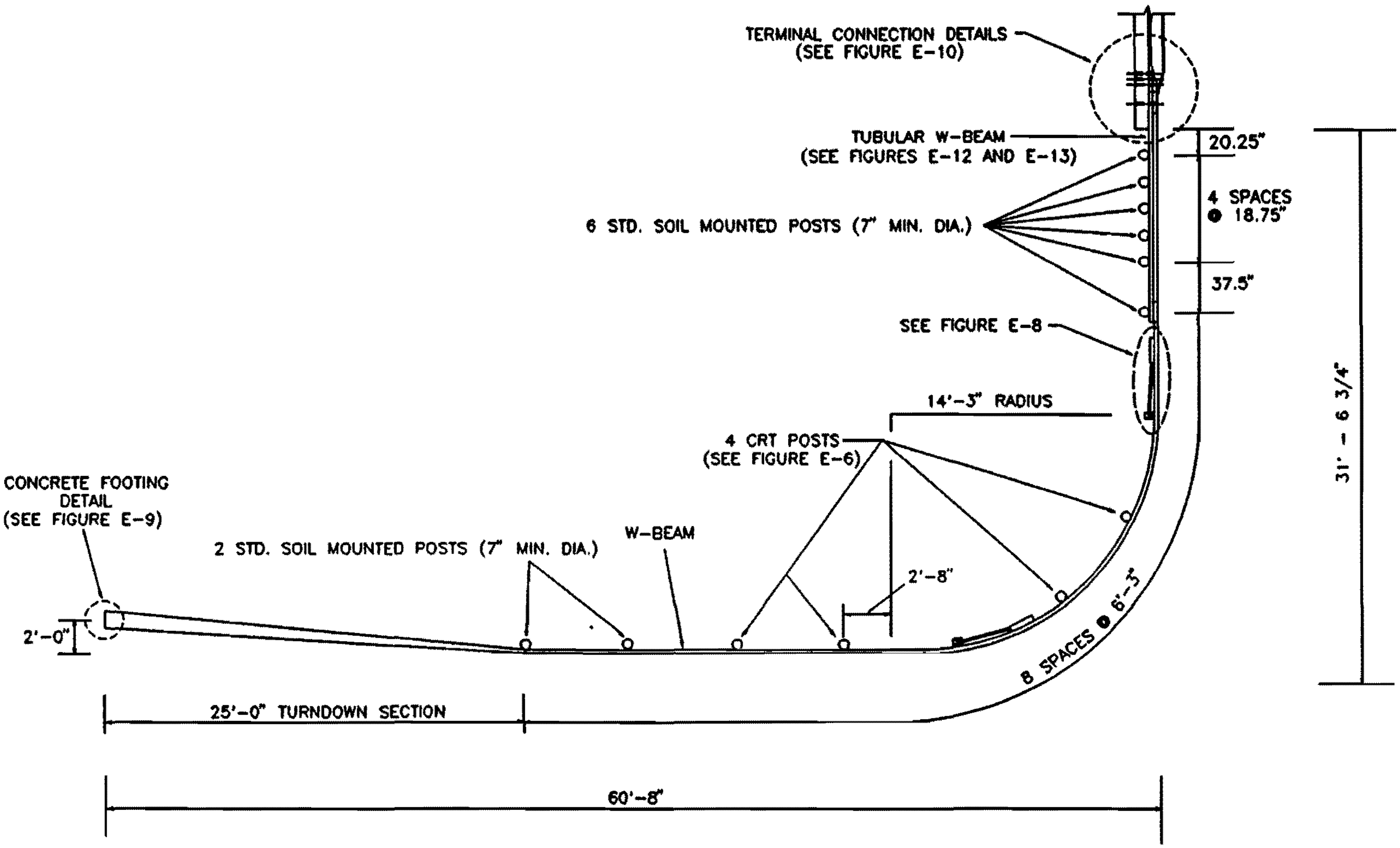


FIGURE E-1. Test 1263-1 Installation Layout

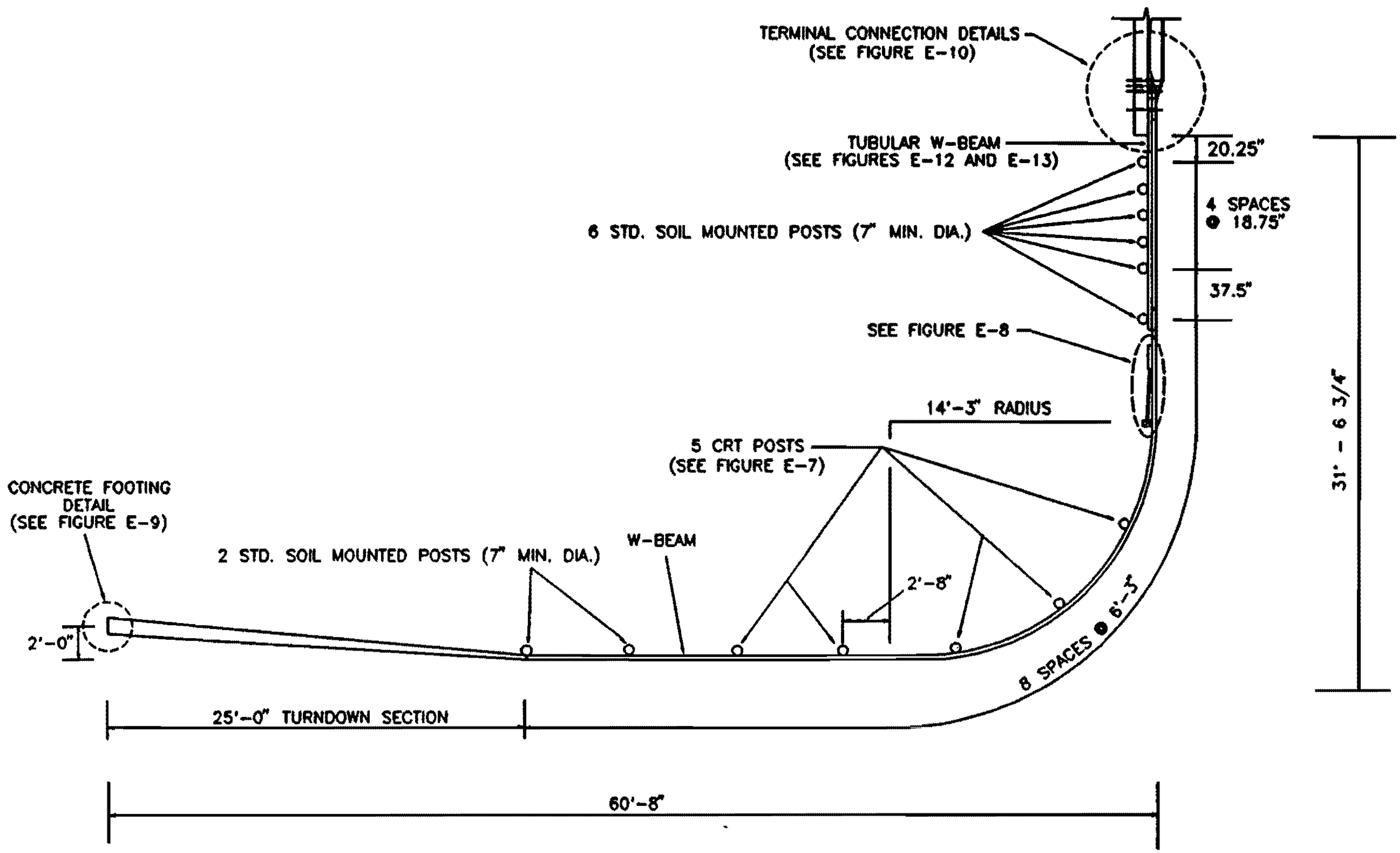


FIGURE E-2. Test 1263-2 Installation Layout

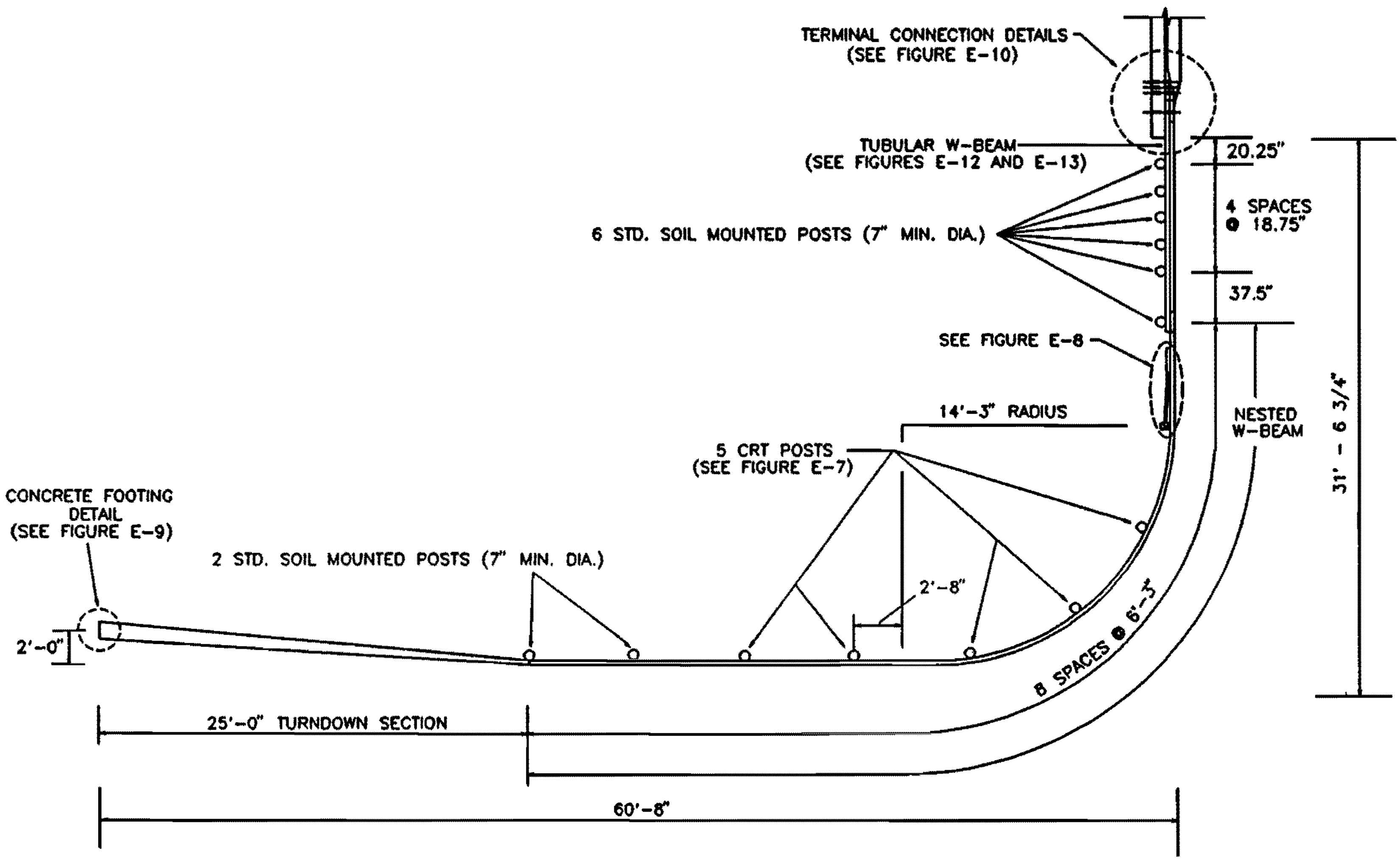


FIGURE E-3. Test 1263-3 Installation Layout

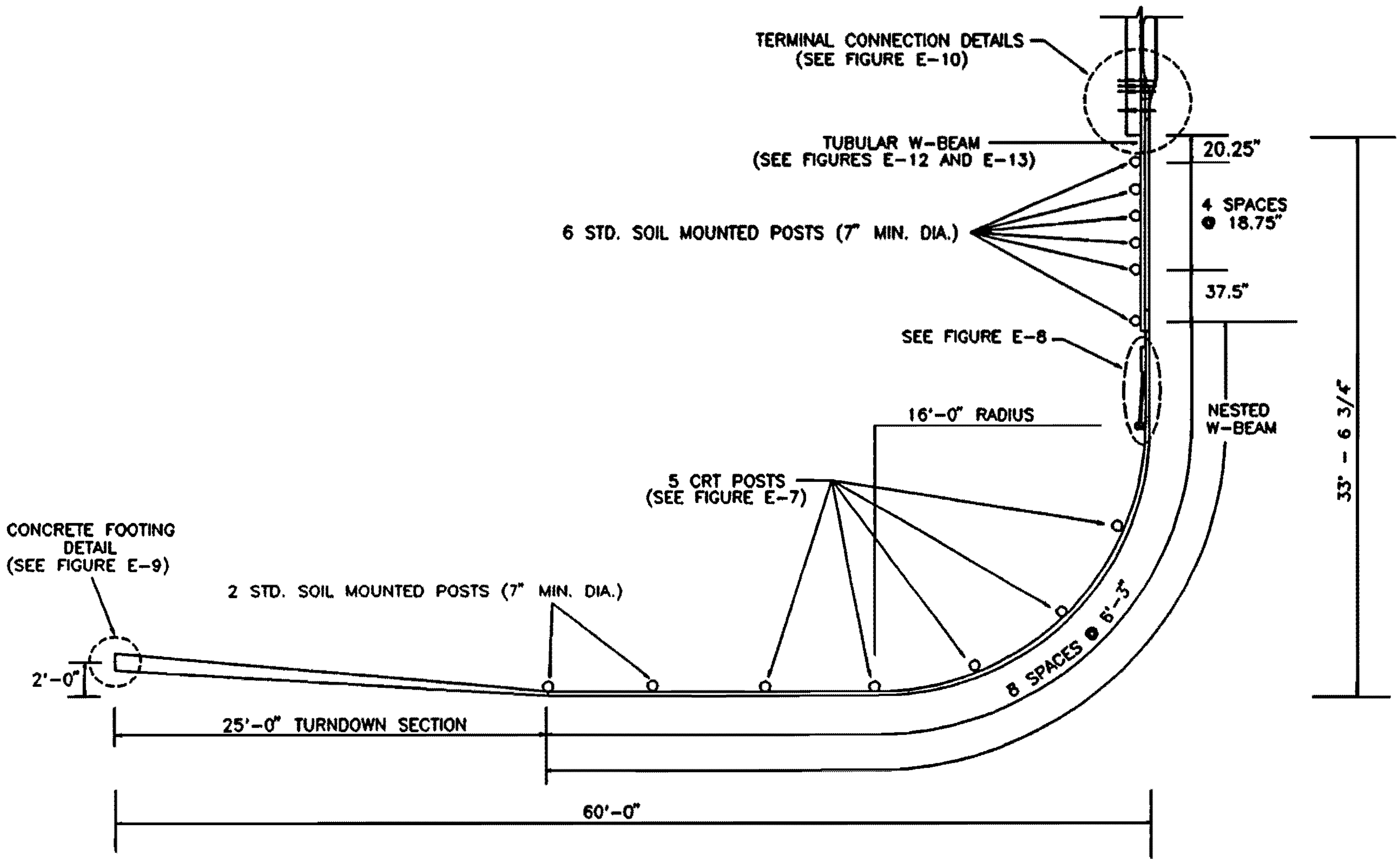


FIGURE E-4. Test 1263-4 and Test 1263-5 Installation Layouts

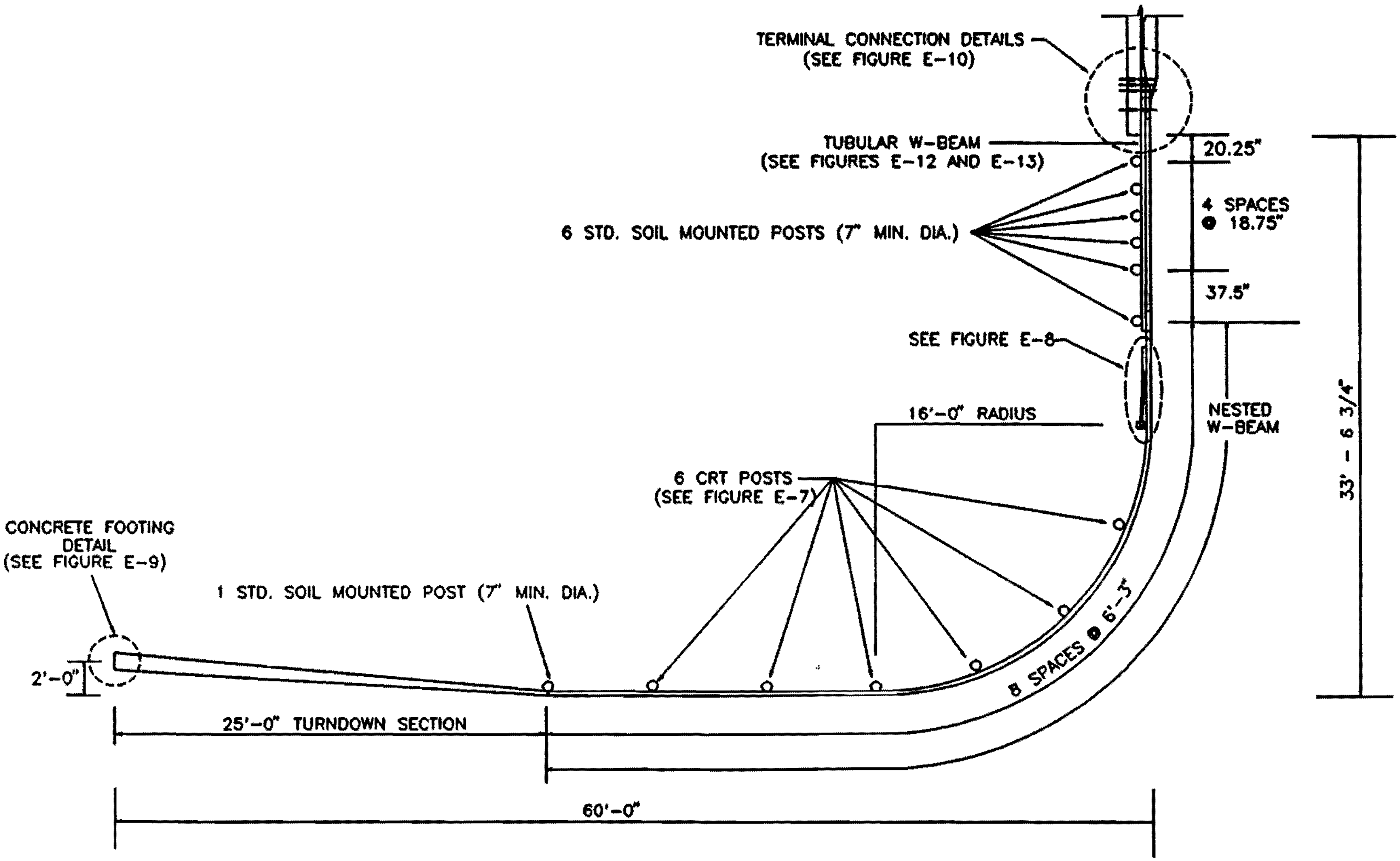


FIGURE E-5. Test 1263-6 Installation Layout

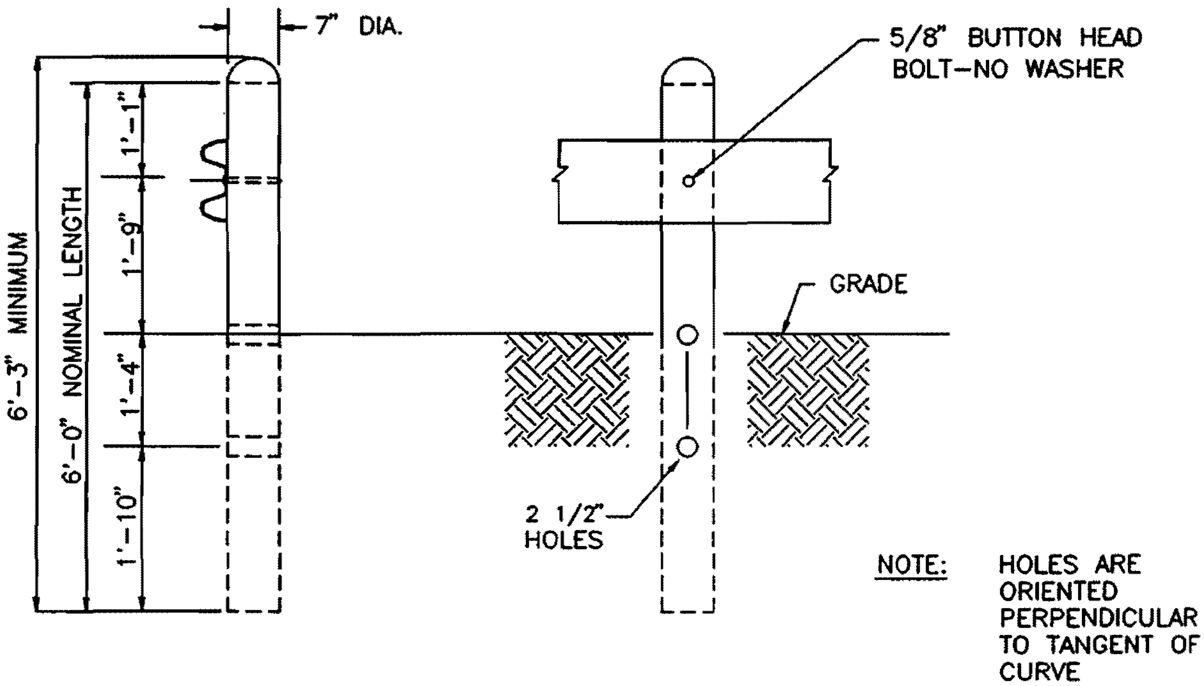


FIGURE E-6. Modified Round Controlled Release Terminal (CRT) Post Used In Test 1263-1

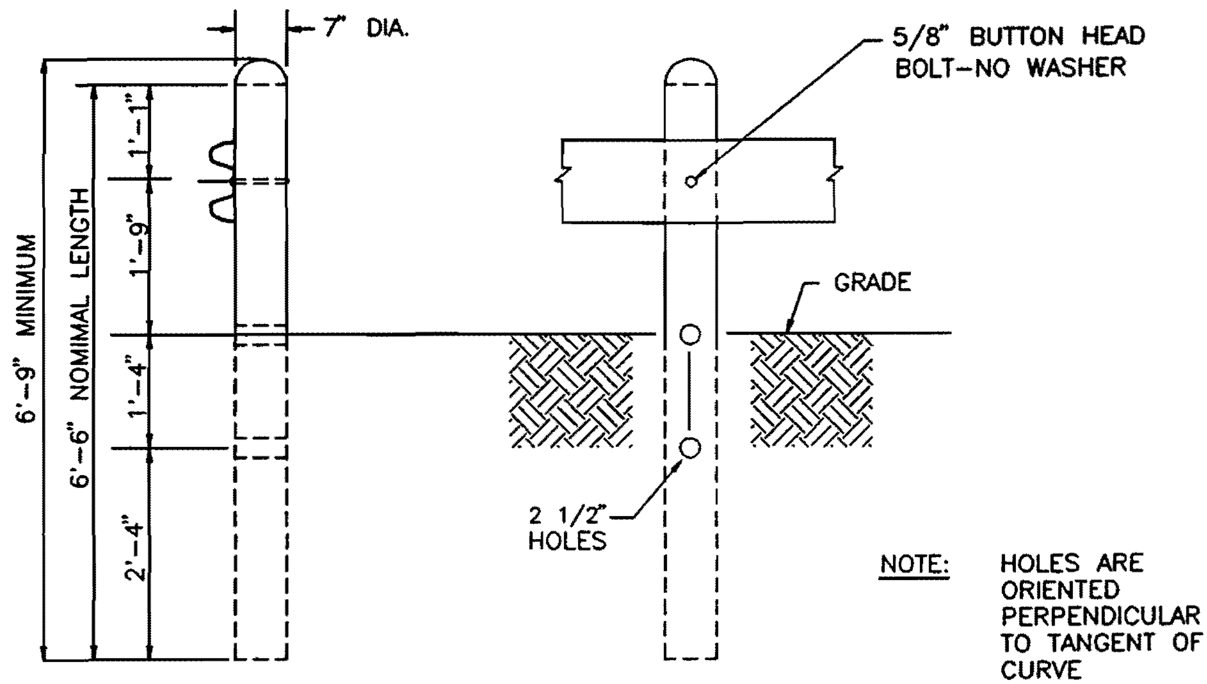


FIGURE E-7. Modified Round Controlled Release Terminal (CRT) Post Used In Tests 1263-2 Through 1263-6

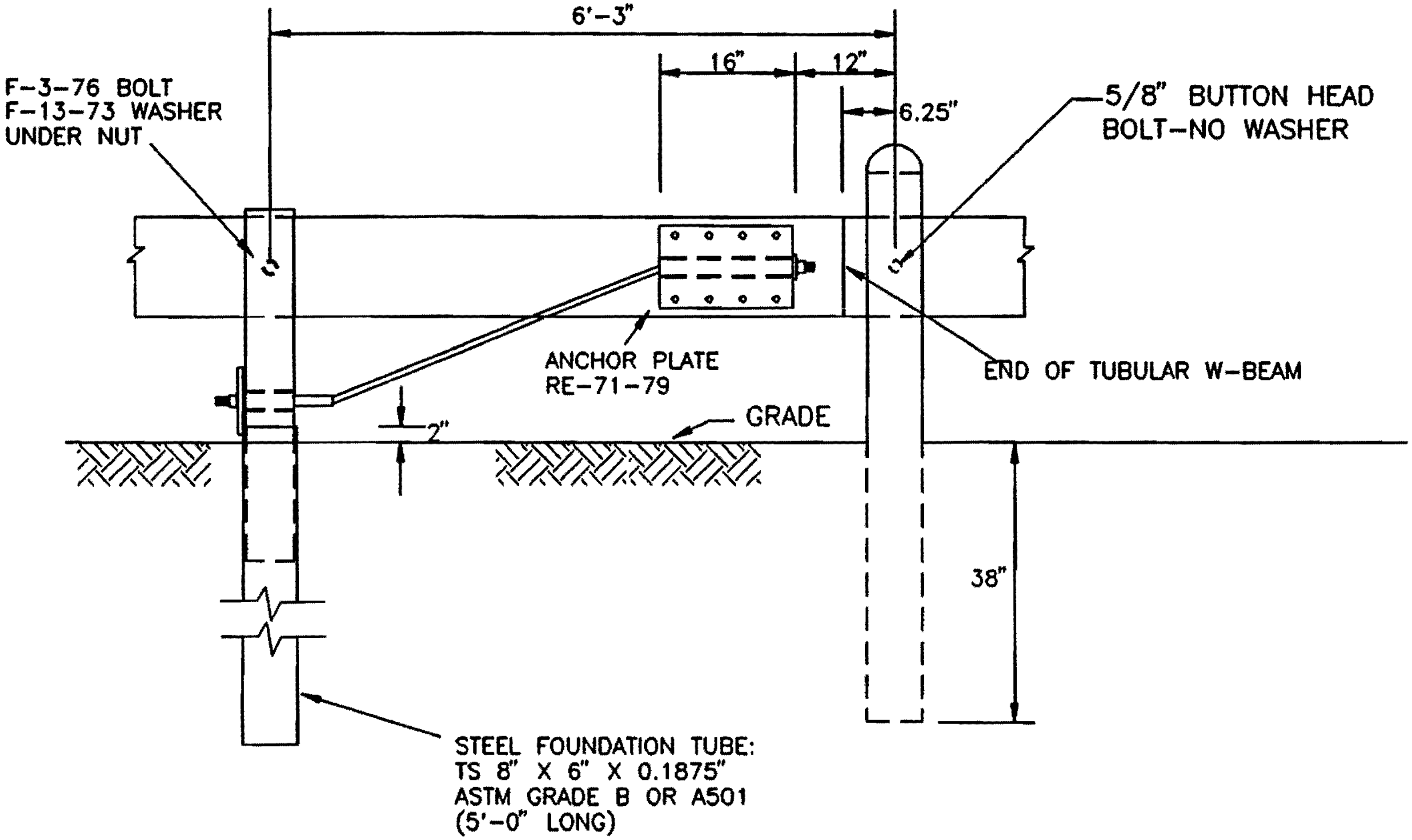


FIGURE E-8. Breakaway Cable Terminal (BCT) Assembly

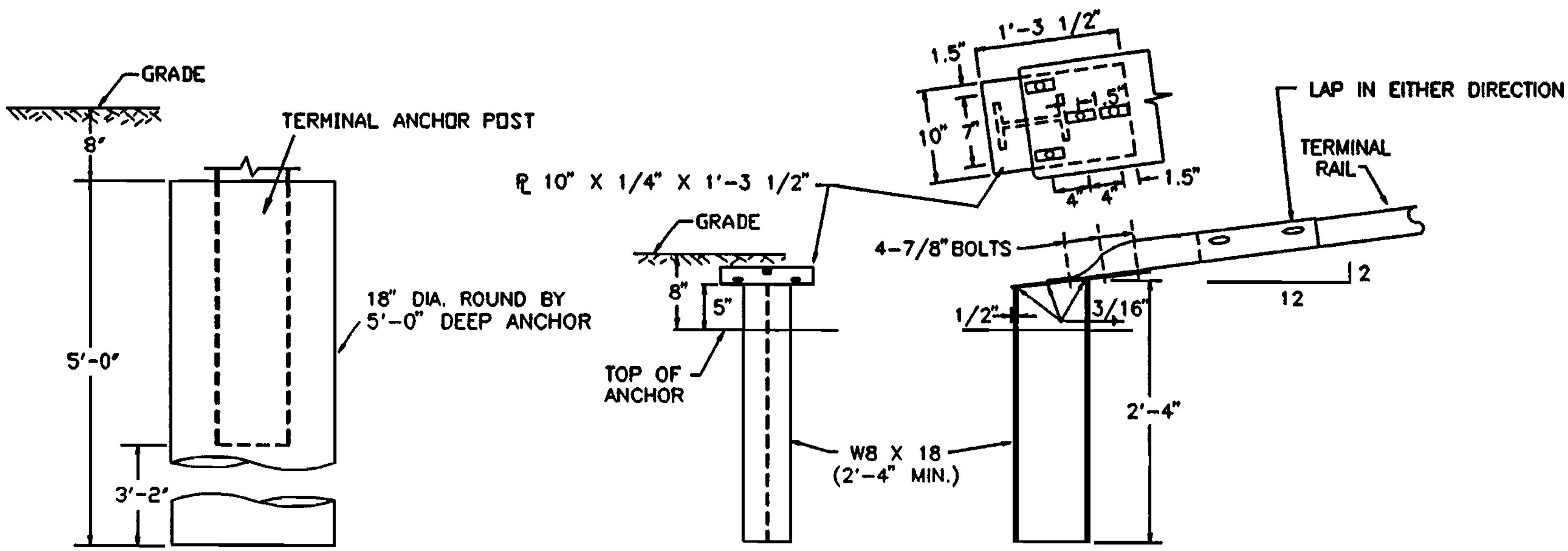


FIGURE E-9. Terminal Concrete Anchor and Anchor Post Details

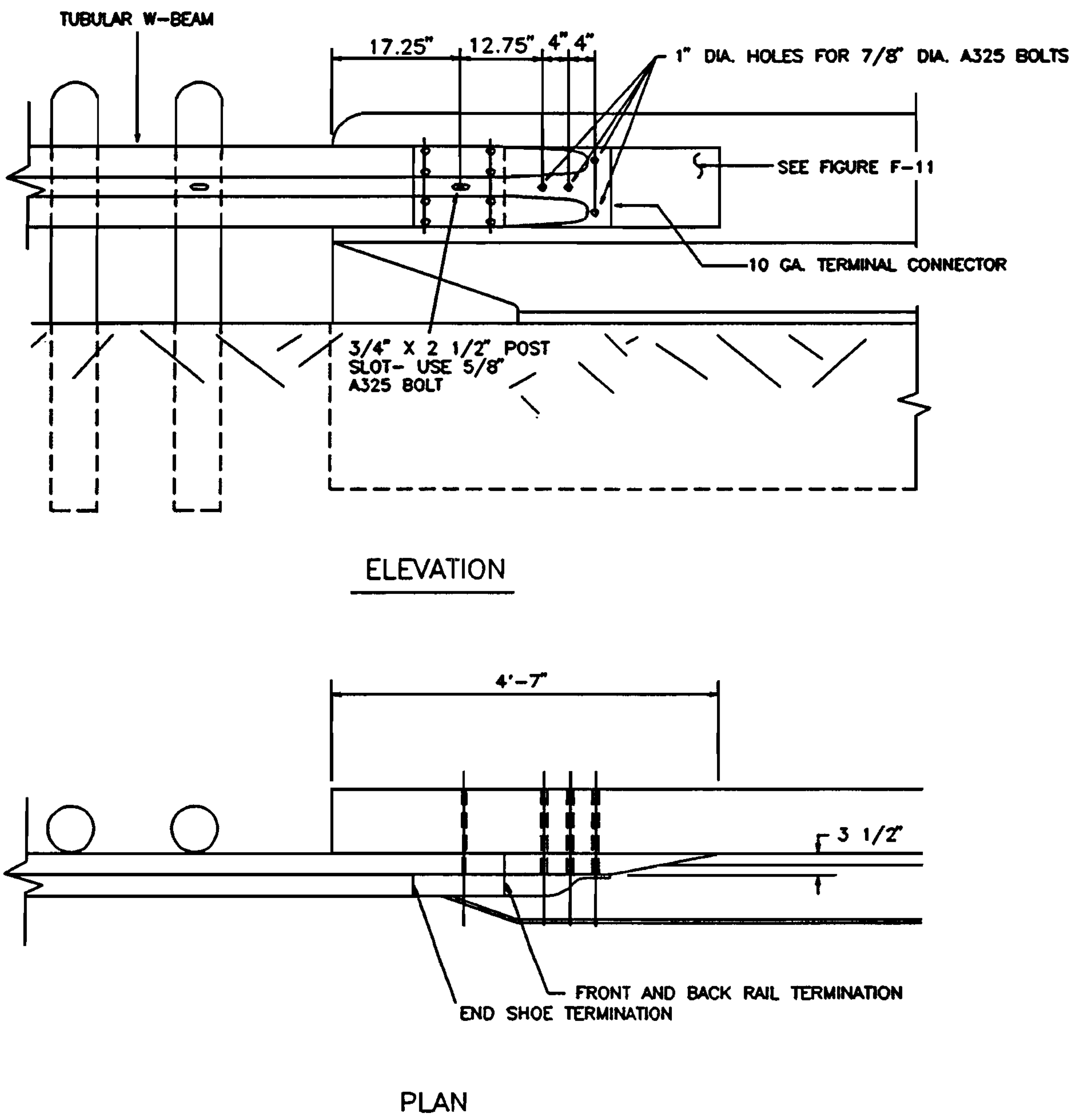


FIGURE E-10. Terminal Connection to Safety Shape as Used in Tested Installation

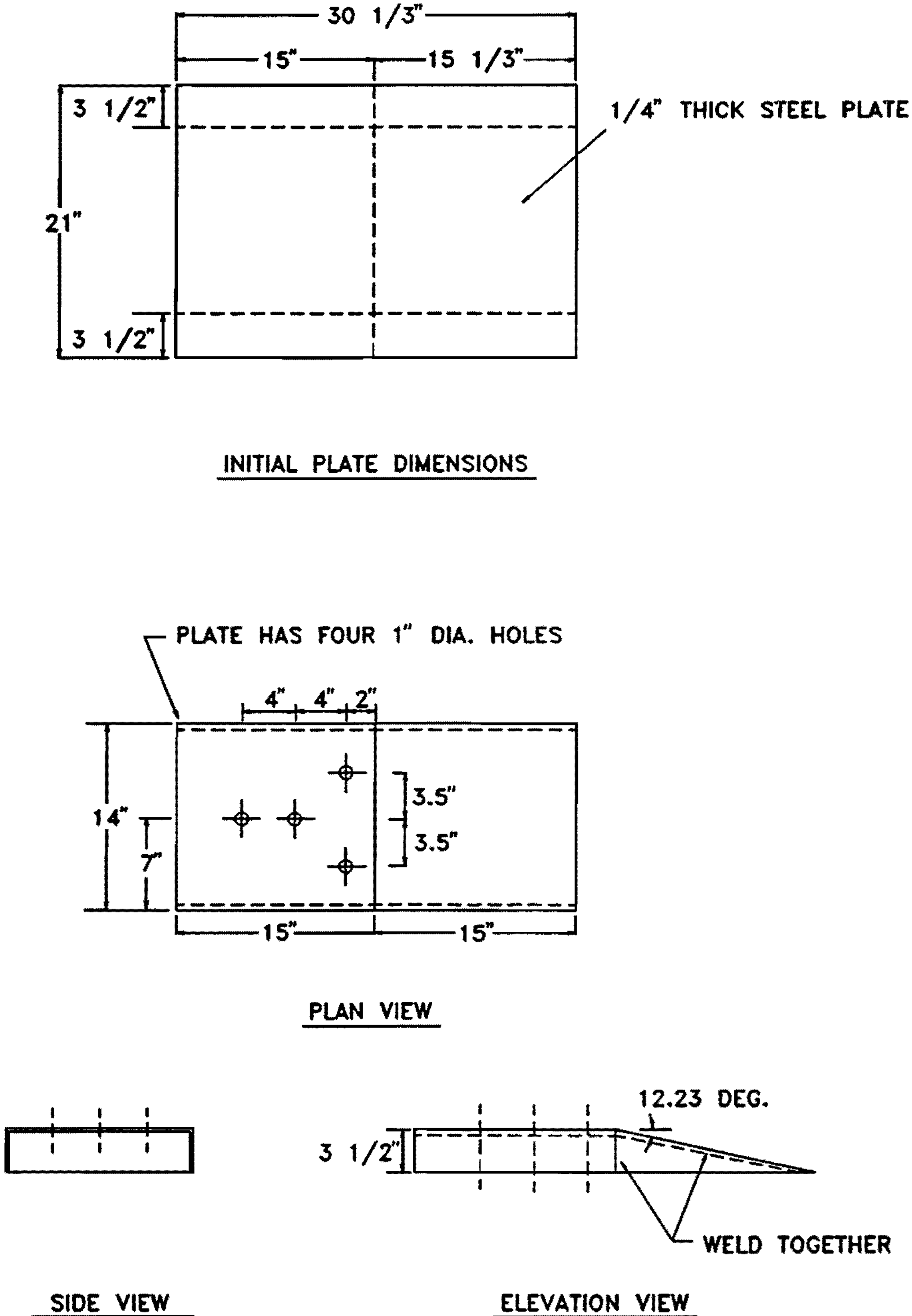


FIGURE E-11. Details of Steel Blockout as Used in Tested Installation

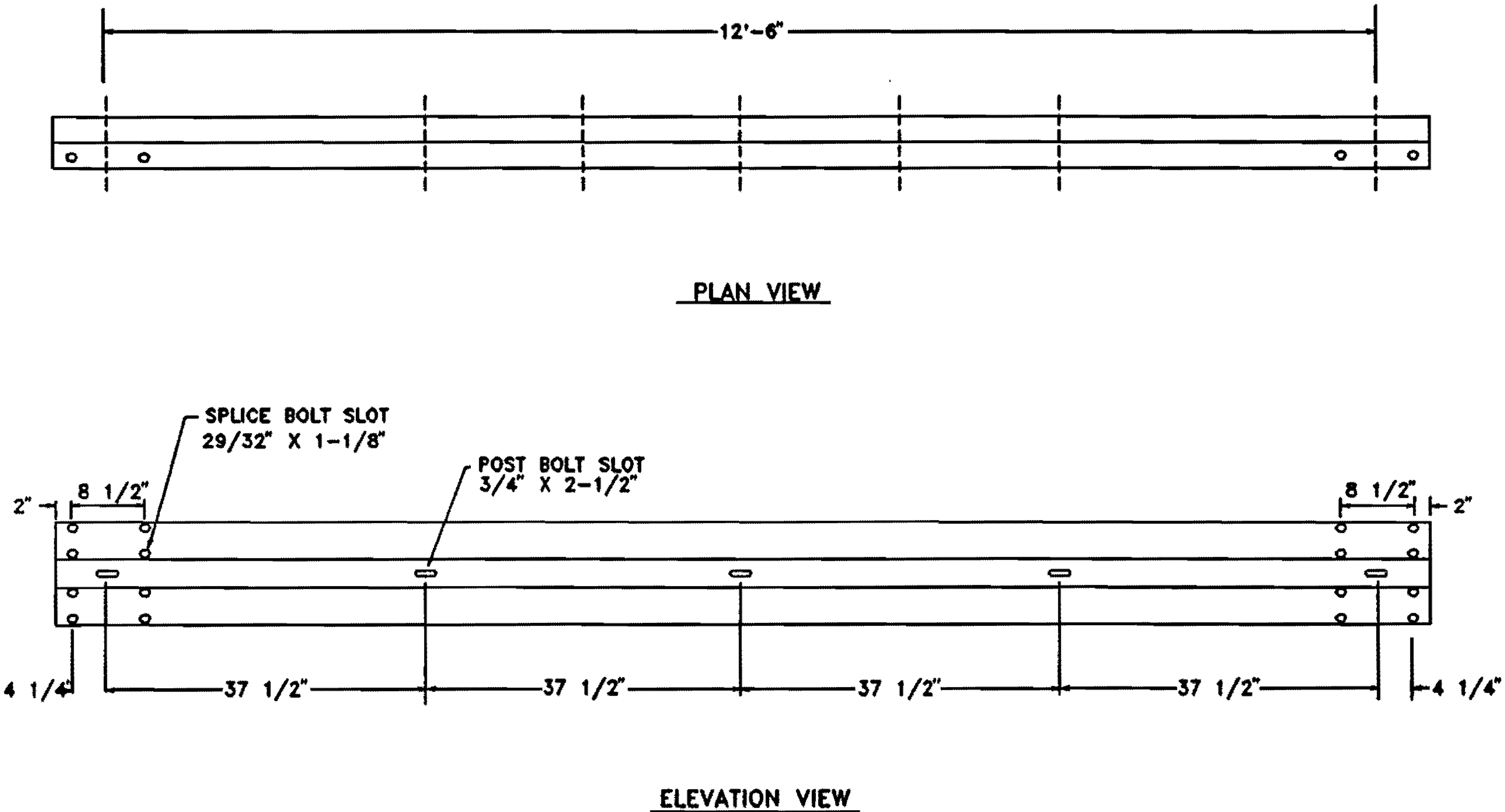
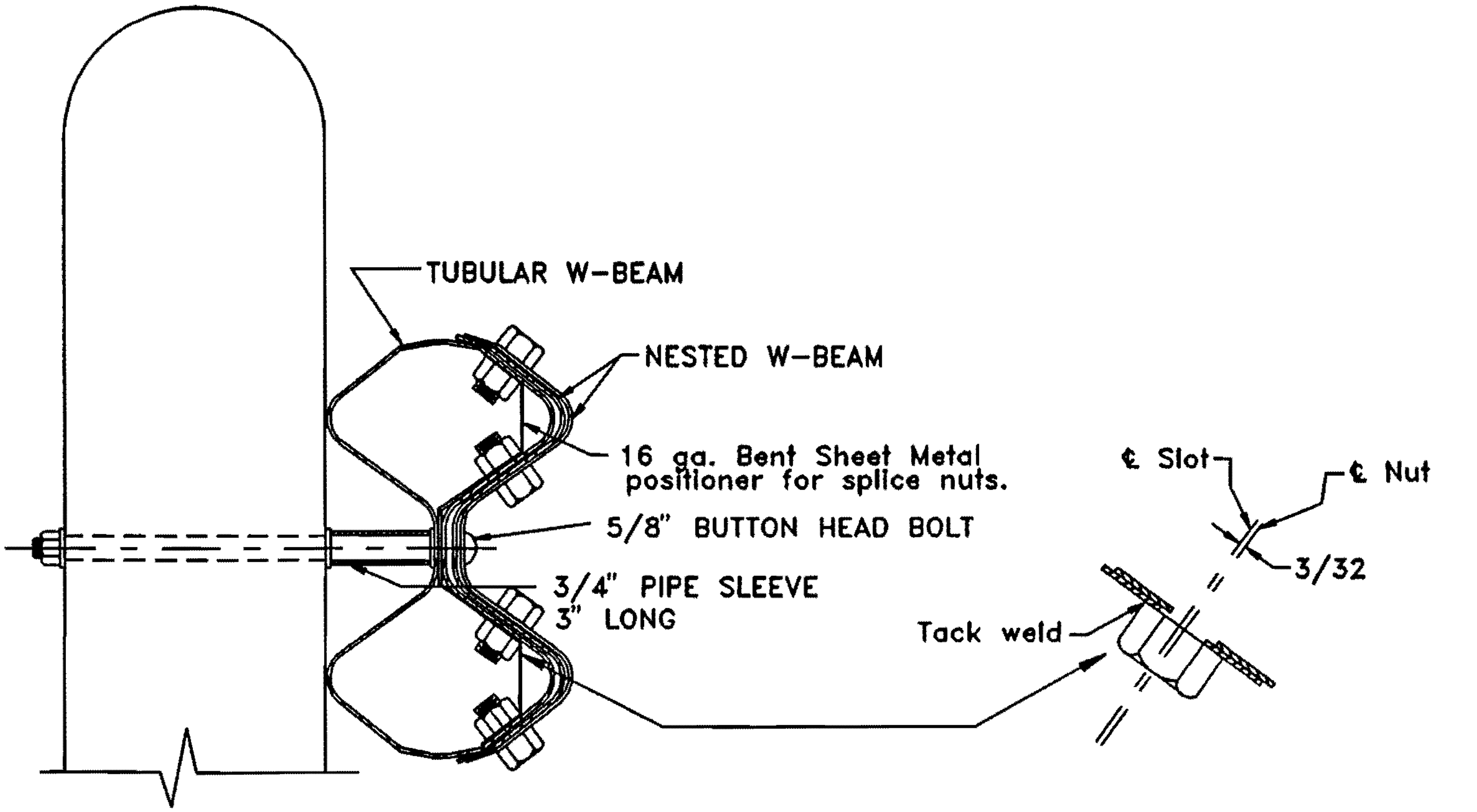
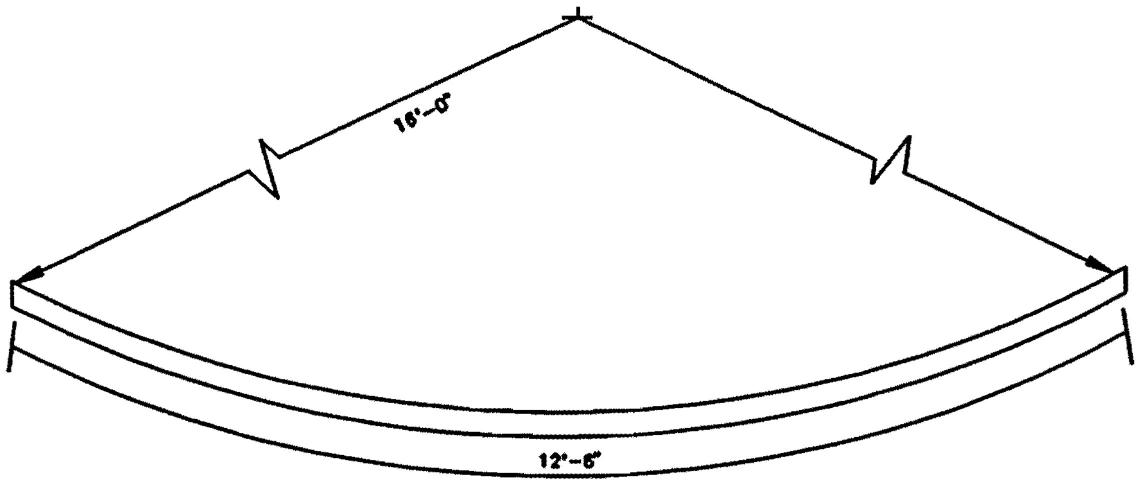


FIGURE E-12. Tubular W-Beam as Installed in Tested Installation.



<u>NOTE</u>: 8~5/8" Splice nuts shall be tacked inside front rail of Tubular W-Beam. The nuts must be tacked approx. 3/32" off the center of the bolt slot toward the outside of the tube. Optionally, the nuts may be tacked to a bent sheet metal positioner as shown. Other suitable positioning methods or devices may be substituted. The complete splice shall have 8 bolts

FIGURE E-13. Tubular W-Beam Connection Details



ENTIRE SECTION CURVED AT 16'-0" RADIUS

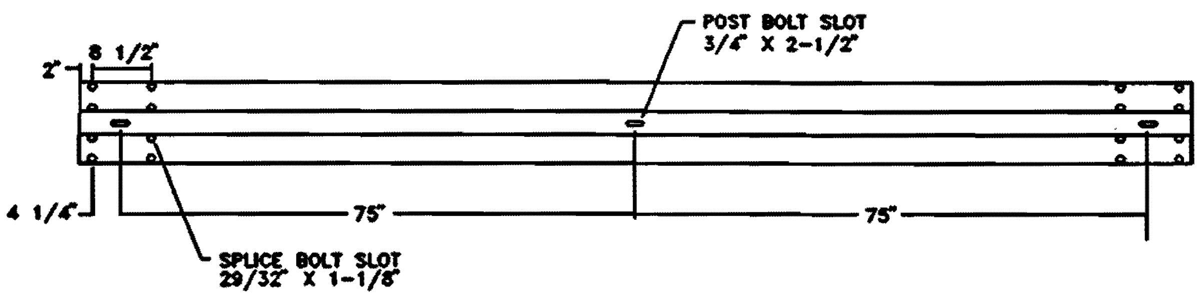


FIGURE E-14. Prefabricated Section of W-Beam as Used in Radius of Tested Installation

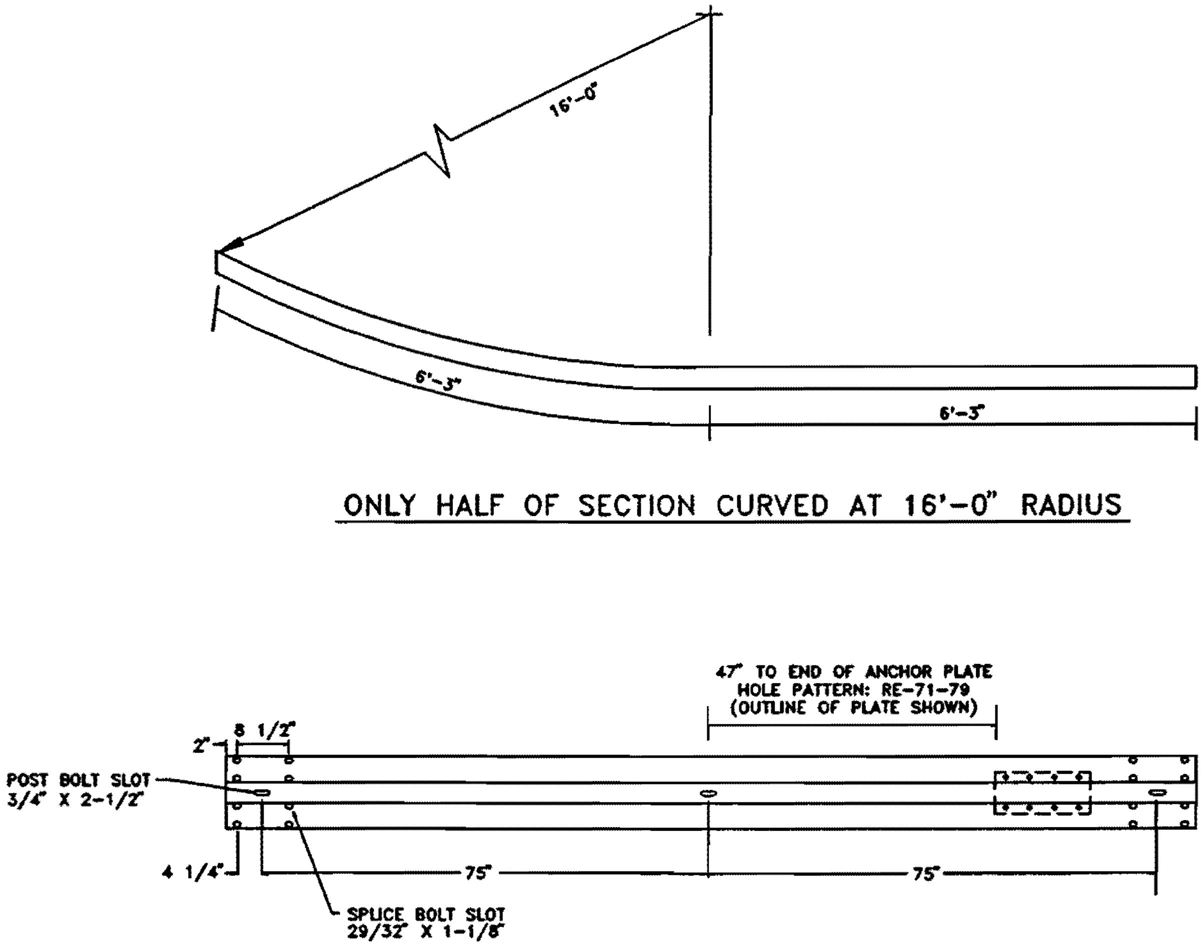


FIGURE E-15. Prefabricated Section of W-Beam as Used at Edge of Radius of Tested Installation

APPENDIX F

CRASH TEST ANALYSIS

CRASH TEST PROCEDURES

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 guardrail system.

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 two computer 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 initial impact.

Photographic Instrumentation and Data Processing

Photographic coverage of the test included four 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 guardrail at the downstream end; a third placed perpendicular to the front of the guardrail and the fourth placed perpendicular to the rear of the guardrail. A flash bulb activated by pressure sensitive tapeswitches was positioned on the impacting vehicle to indicate the instant of contact with the guardrail 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 professional video camera and 3/4-in video recorder along with 35-mm cameras were used for documentary purposes and to record conditions of the test vehicle and guardrail before and after the test.

Test Vehicle Propulsion and Guidance

The test vehicles were towed into the guardrail system 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 guardrail system, 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.

CRASH TEST RESULTS

All crash tests and data analysis were conducted in accordance with guidelines contained in National Cooperative Highway Research Program (NCHRP) Report 230 (3). A detailed description of the test results, including sequential photographs, accelerometer traces, and rate gyro data are presented below.

Test 1263-1 (1,800 lb/58.4 mph/20.5 deg)

A 1987 Yugo GV (Figures F-1 and F-2) was used in the initial crash test of the short radius guardrail shown in Figures F-3 through F-6. Test inertia mass of the vehicle was 1,800 lb (817 kg) and its gross static mass was 1,970 lb (894 kg). The height to the lower edge of the vehicle bumper was 14.25 in. (36.2 cm), and the height to the upper edge was 19.75 in. (50.2 cm). Additional dimensions and information on the test vehicle are given in Figure F-7. The vehicle was directed into the guardrail as shown in Figure F-8 using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the guardrail at a speed of 58.4 mi/h (94.0 km/h) and at an angle of 20.5 degrees relative to the tangent of the guardrail along the primary roadway.

Upon impact, the posts in the curved section of rail began to deflect in the soil. Although post 7 fractured at the ground line as designed, posts 8 and 9 rotated in the soil and were subsequently pulled from the ground. As the rail continued to deflect, the cable of in-line BCT anchor tightened and prevented post 10 from failing. The tension which developed in the cable anchor prevented further deflection of the rail on the upstream end of the curve, causing the vehicle to pitch forward and yaw significantly in counter-clockwise rotation. After yawing a total of 167 degrees, the vehicle came to rest on top the guardrail near post 8. Sequential photographs of the impact are shown in Figures F-9 and F-10.

As can be seen in Figures F-11 through F-14, the short radius system experienced extensive damage. Posts 8 and 9 were pulled out of the ground and post 7 fractured at ground level. Post 10 was deflected backwards, cracked at the base, and split longitudinally. The guardrail in the curved section was bent and pulled loose from posts 8 and 9. A maximum dynamic deflection of 9.7 ft (3.0 m) occurred at post 9, and the maximum residual deformation

FIGURE F-l. Vehicle Prior to Test 1263-1

FIGURE F-2. Anthropometric Dummy before Test 1263-1

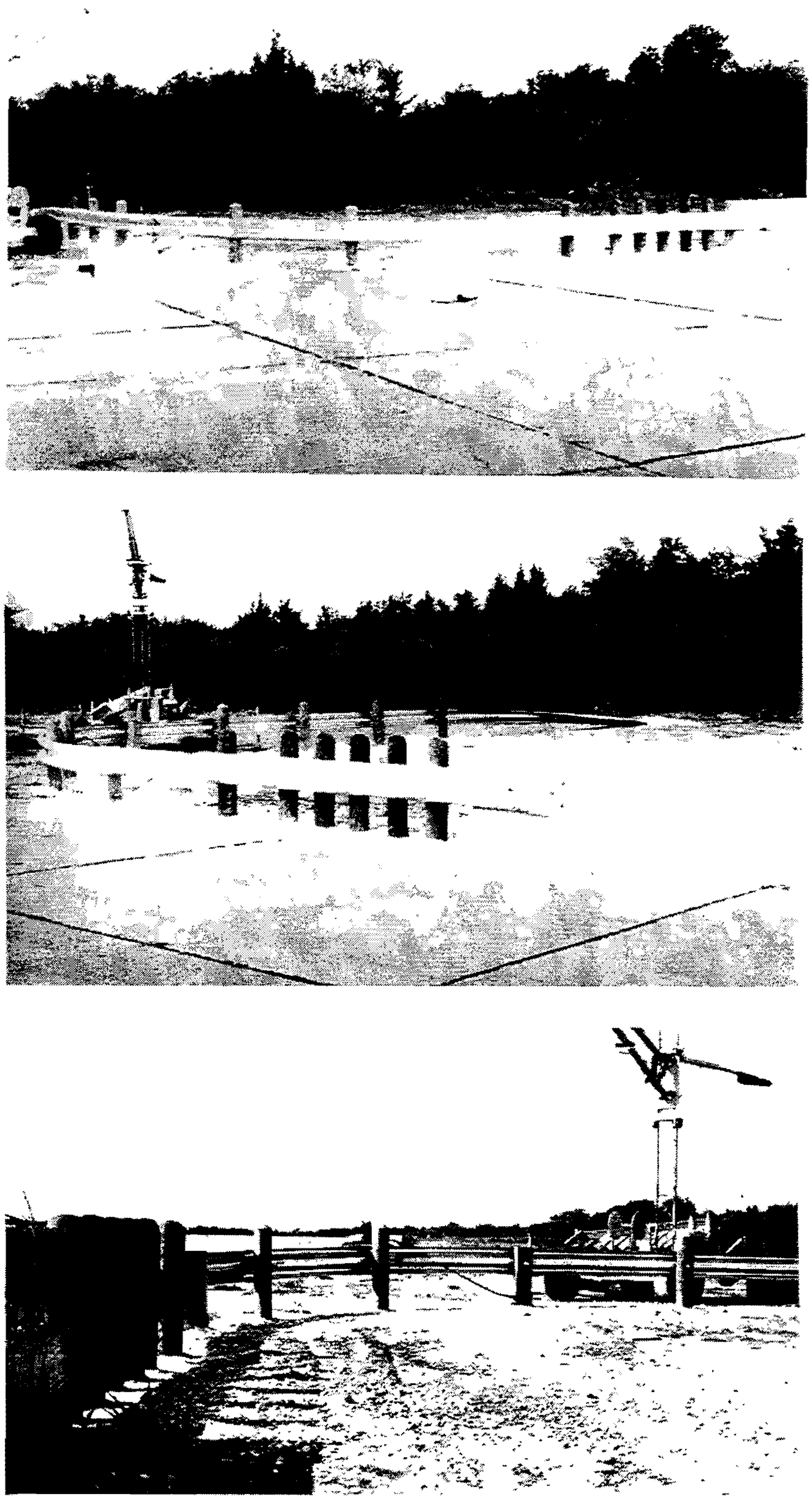
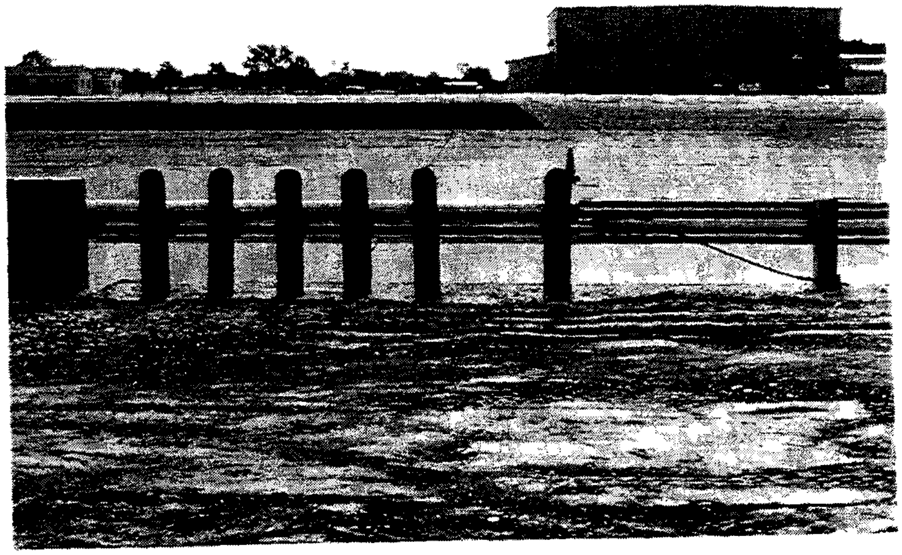


FIGURE F-3. Short Radius System Prior to Test 1263-1



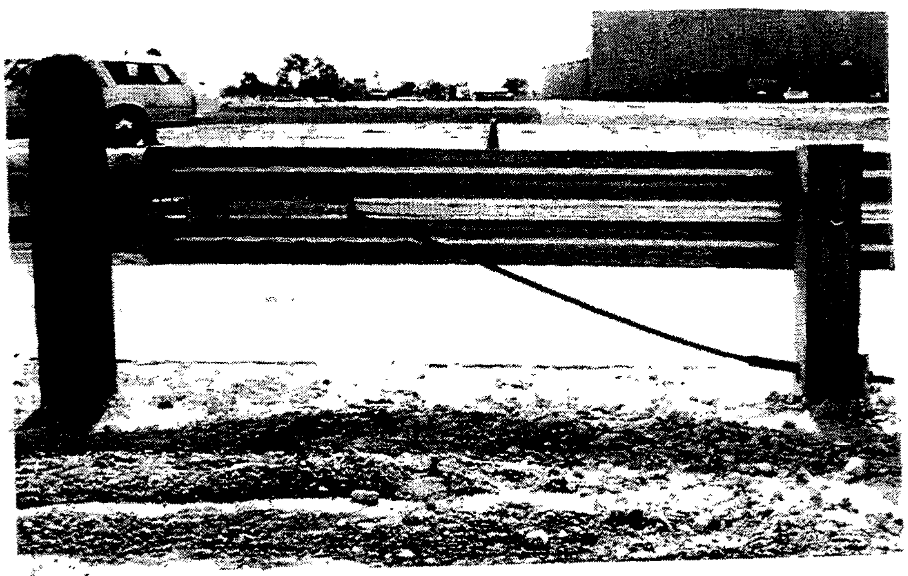
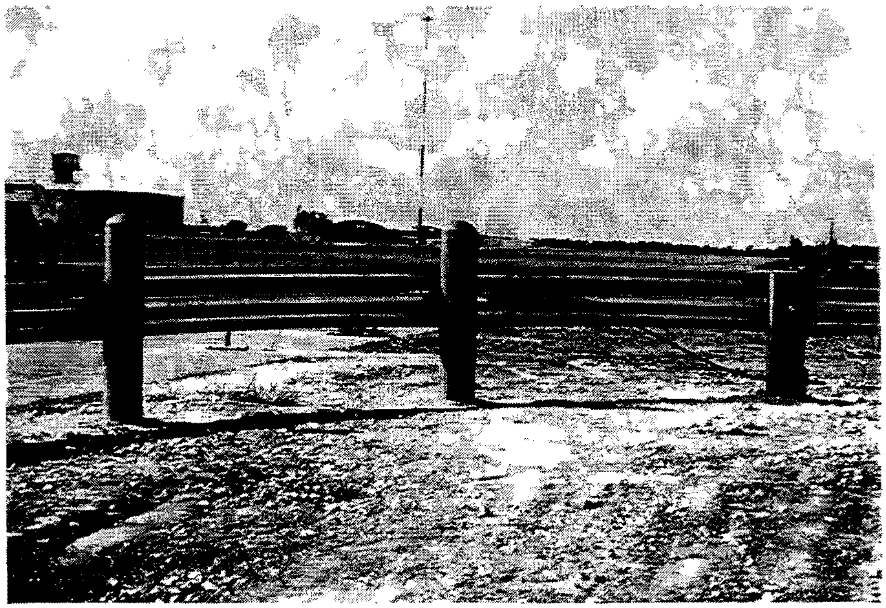


FIGURE F-4. Connection of Curved Section to Bridge Rail for Test 1263-1



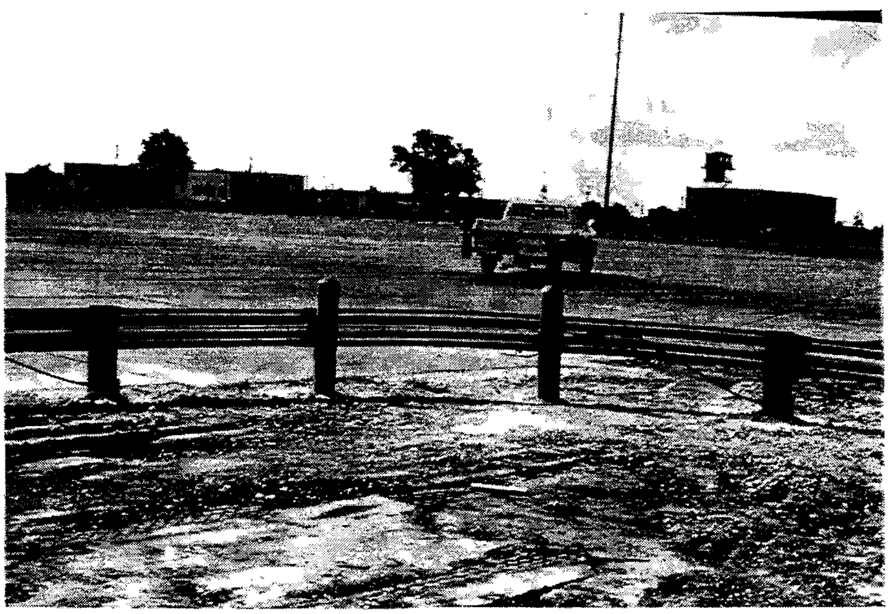


FIGURE F-5. Connection of Curved Section to Turned-Down End for Test 1263-1

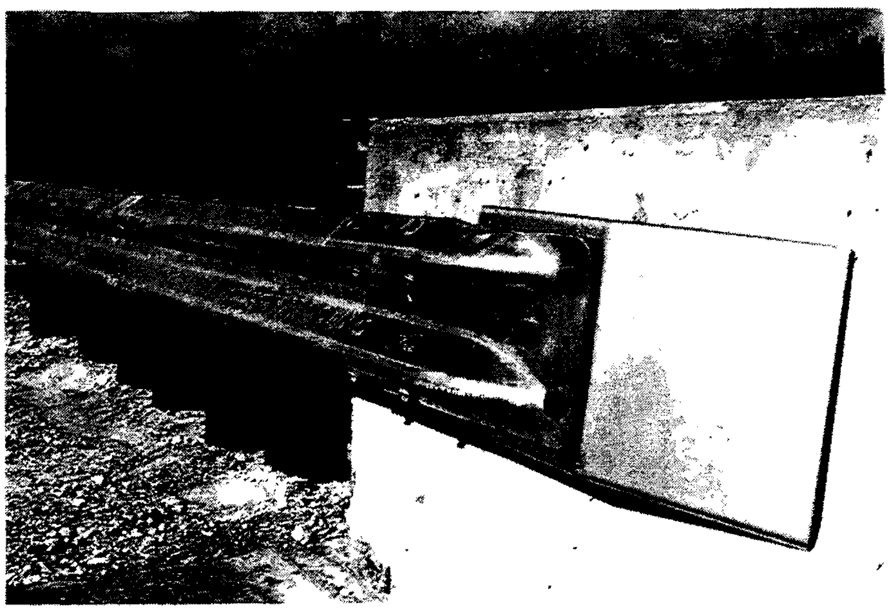
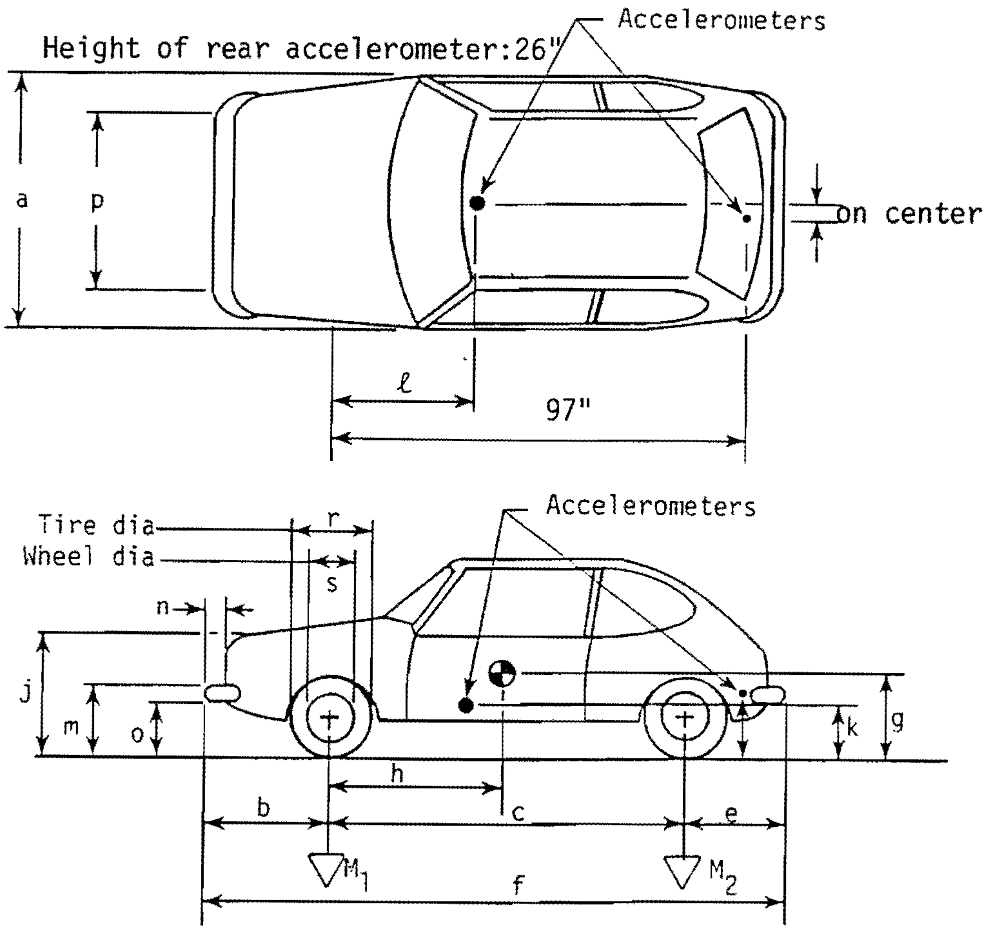


FIGURE F-6. **End Treatments Used on Short Radius Treatment (Test 1263-1)**

Date: 7-29-92 Test No.: 1263-1 VIN: VX1BA1219JK400969

Make: Yugo Model: GV Year: 1987 Odometer: 79295

Tire Size: 145 R13 Ply Rating: ____ Bias Ply: ___ Belted: ___ Radial: X



Tire Condition: good ___ fair X badly worn ___

Vehicle Geometry - inches

a	60"	b	27"
c	85"	d*	55.75"
e	25.5"	f	137.5"
g		h	30.6"
i	----	j	31"
k	15.5"	ℓ	30.5"
m	19.75"	n	3.25"
o	14.25"	p	51.5"
r	22.5"	s	14.25"

Engine Type: 4 cyl

Engine CID: 1100 cc

Transmission Type:

XXXXXXXXXXXX Manual

FWD XXXXXXXXXXXXXX

Body Type: Hatch

Steering Column Collapse Mechanism:

___Behind wheel units
___Convoluted tube
___Cylindrical mesh units
___Embedded ball
___NOT collapsible
___Other energy absorption
___Unknown

Brakes:

Front: disc___ drum___

Rear: disc___ drum___

4-wheel weight for c.g. det. ℓf 583 rf 569 ℓr 317 rr 331

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1206	1152	1236
M_2	626	648	734
M_T	1832	1800	1970

Note any damage to vehicle prior to test:

*d = overall height of vehicle

FIGURE F-7. Test Vehicle Properties (1263-1)

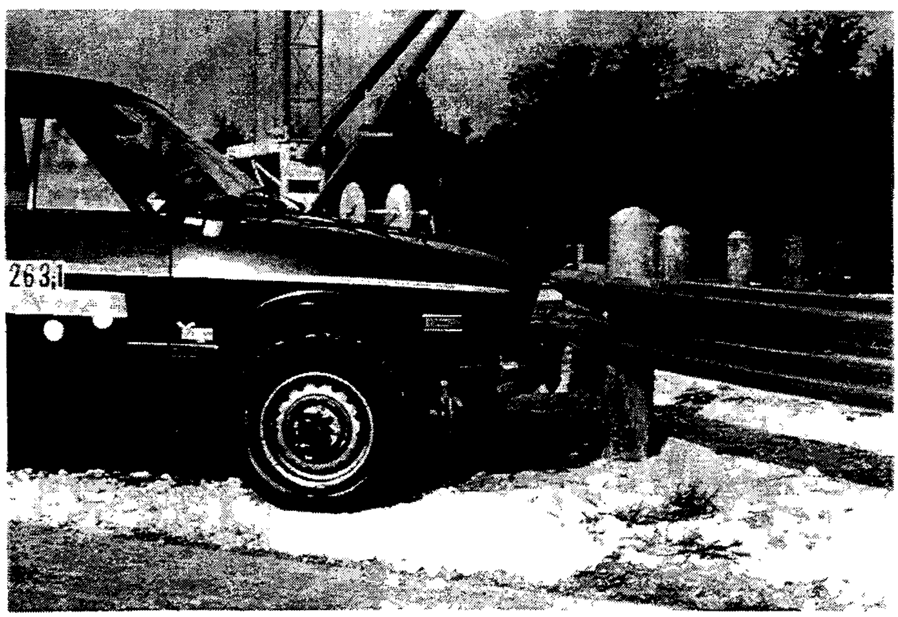


FIGURE F-8. Vehicle/Guardrail Geometrics for Test 1263-1

0.000 s

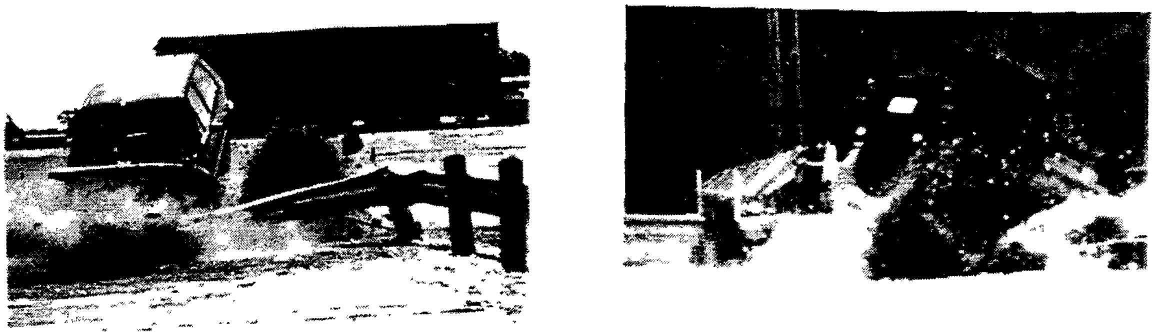
0.074 s

0.150 s

0.224 s

FIGURE F-9. **Sequential Photographs for Test 1263-1 (Perpendicular and Side Views)**

0.300 s



0.374 s

0.450 s

0.524 s

FIGURE F-9. Sequential Photographs for Test 1263-1 (Perpendicular and Side Views) (continued)

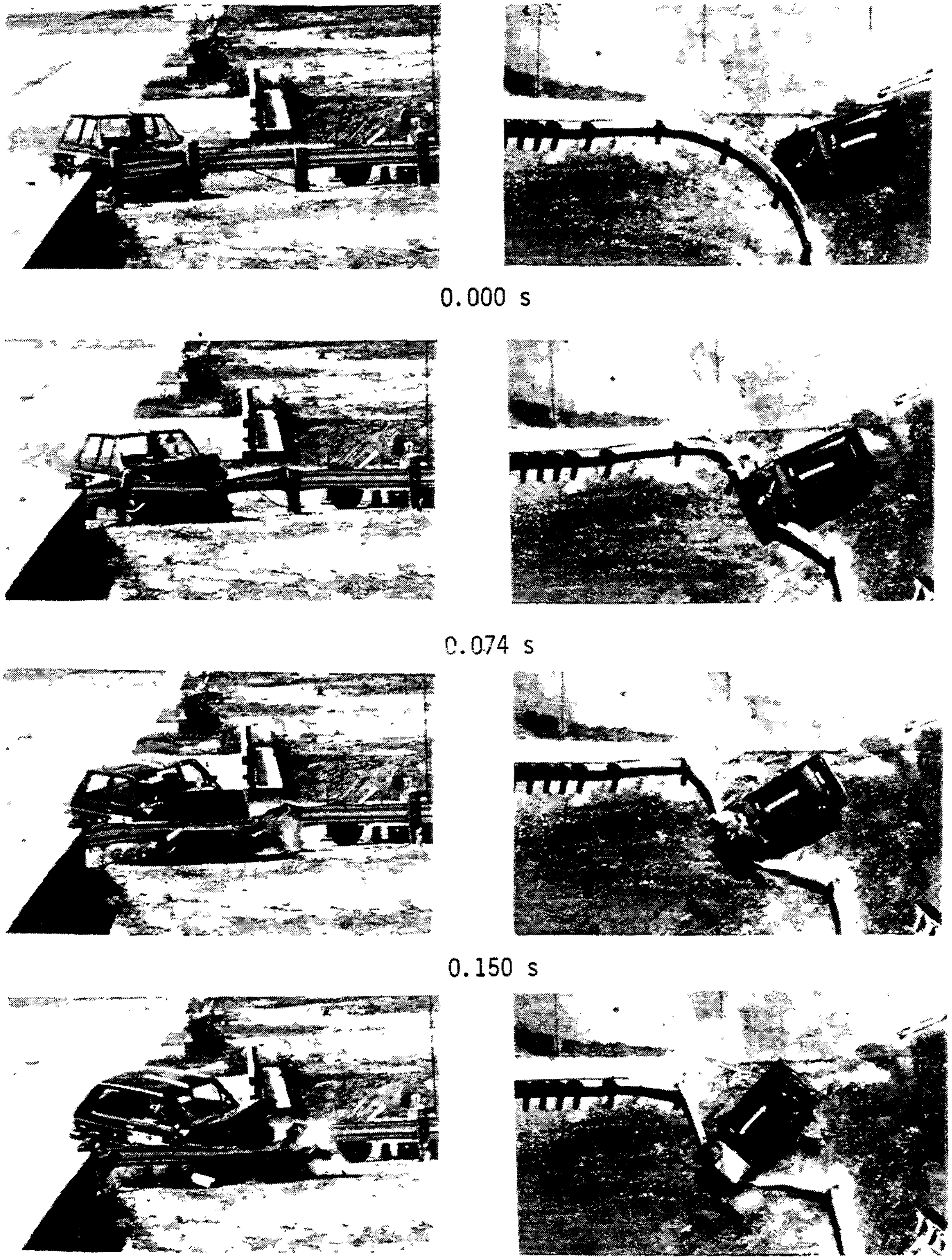
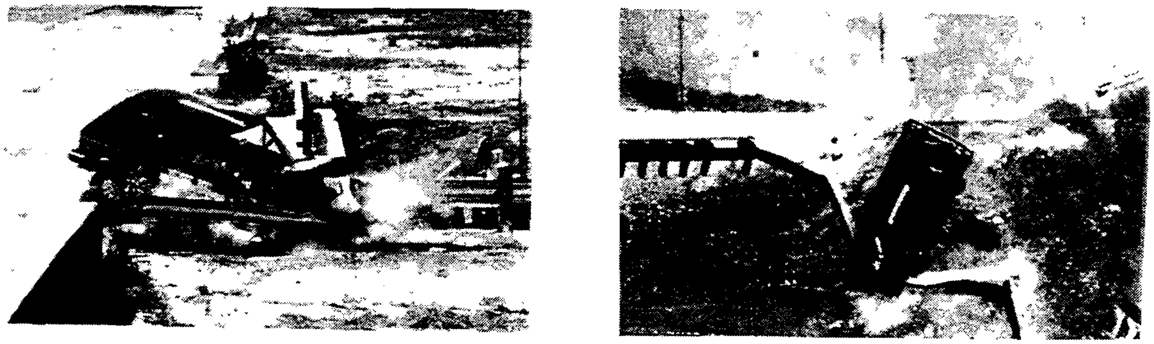
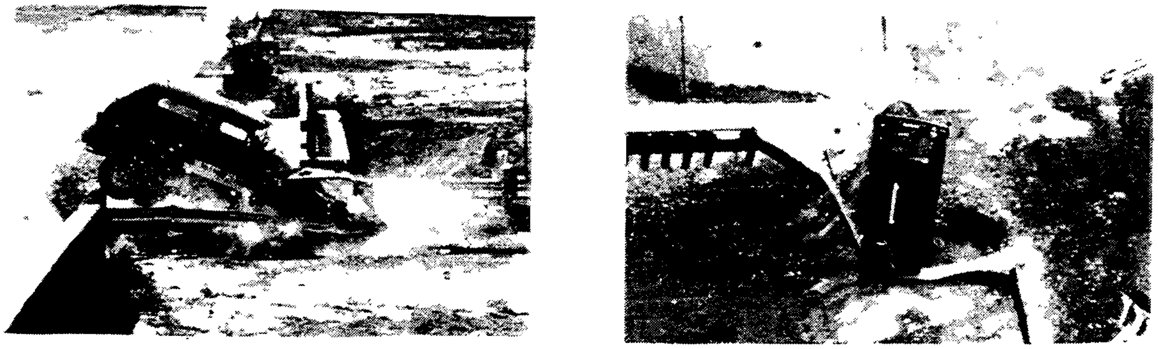


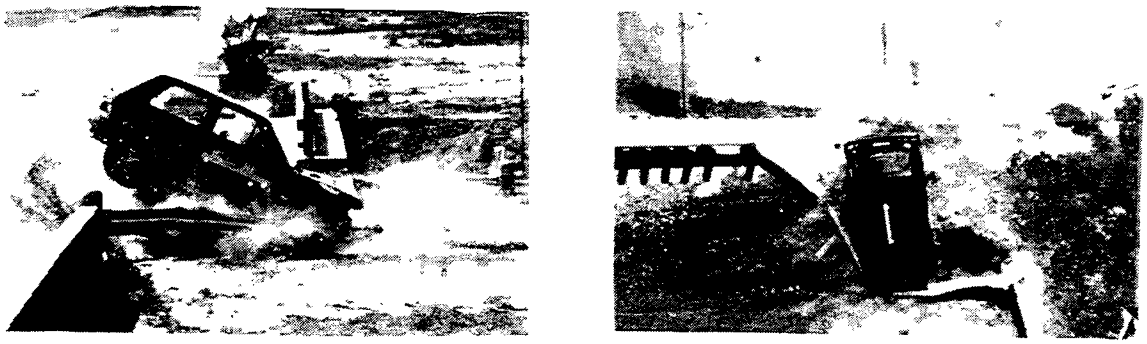
FIGURE F-10. Sequential Photographs for Test 1263-1 (Frontal and Overhead View)



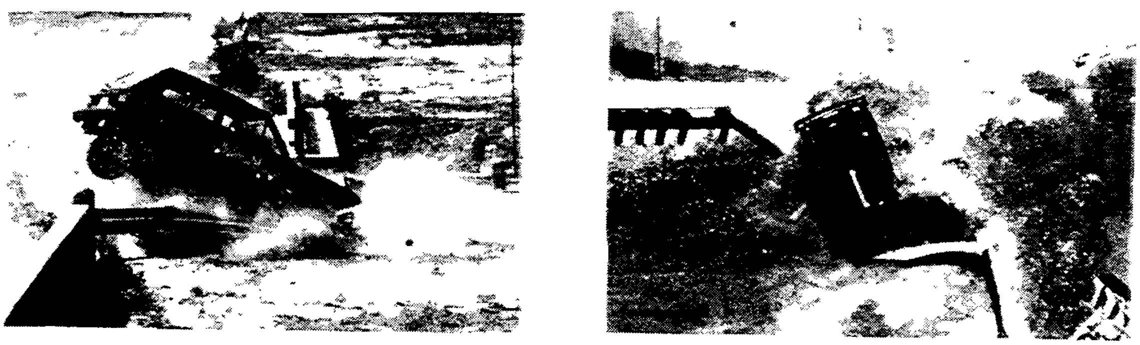
0.300 s



0.374 s



0.450 s



0.524 s

FIGURE F-10. Sequential Photographs for Test 1263-1 (Frontal and Overhead View) (continued)

FIGURE F-11. Site after Test 1263-1

FIGURE F-12. Damage at Post 7, Test 1263-1

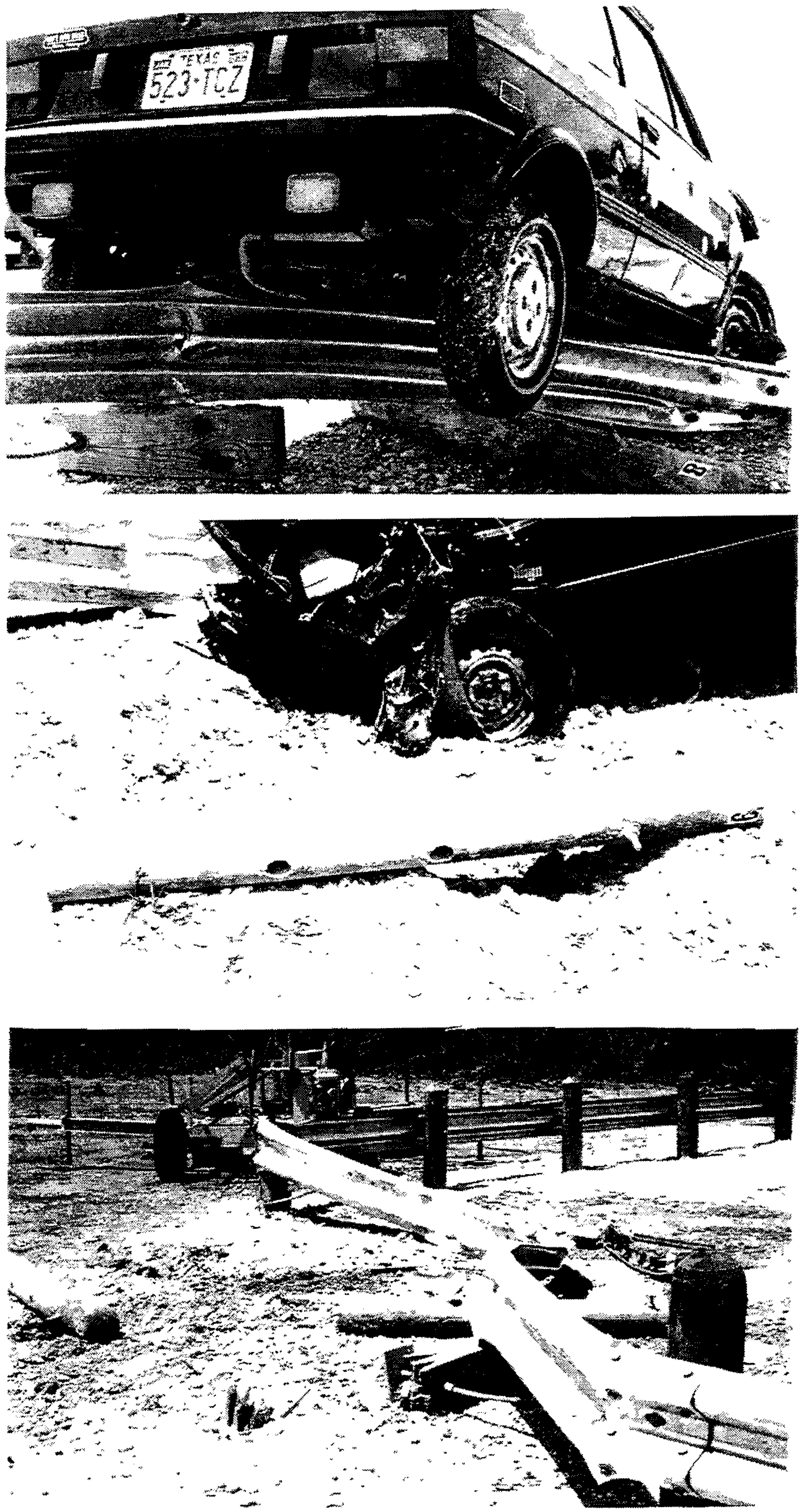


FIGURE F-13. Damage at Posts 8 and 9, Test 1263-1

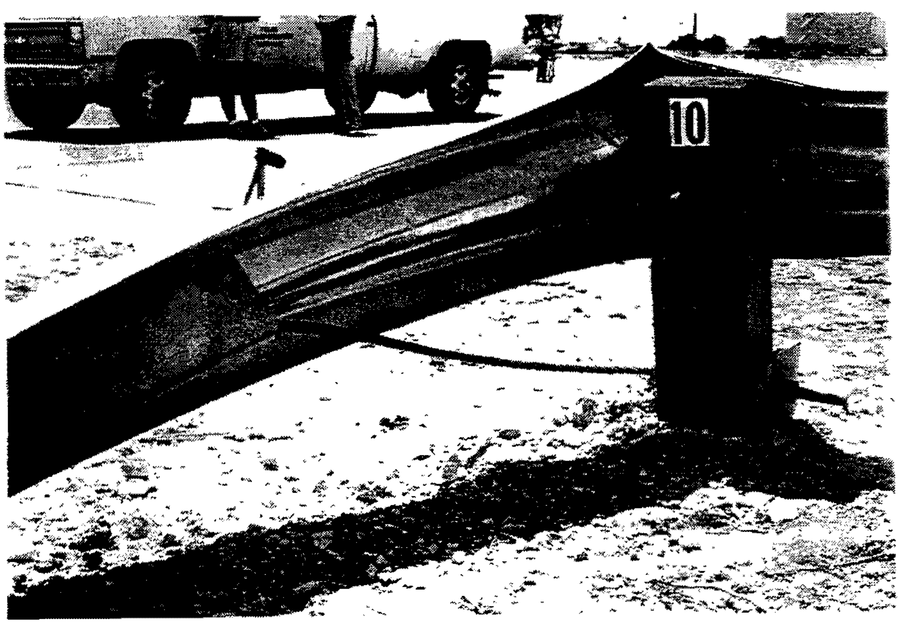


FIGURE F-14. Damage at Post 10, Test 1263-1

was 6.0 ft (1.8 m) at this same location. Measurement of the movement of the rail element at posts 7 through 10 were taken and reported for specific times as noted in Table F-1.

The damage to the vehicle is shown in Figures F-15 and F-16. Maximum crush at bumper height was 15.5 in. (39.4 cm) and 8.5 in. (21.6 cm) at the left and right front corners of the vehicle respectively. The wheelbase on the driver's side was reduced by 9.0 in. (22.9 cm). The driver's door was deformed outward 2.0 in. (5.1 cm) and the driver's side window was broken out. There were two dents in the roof above the rear passenger compartment: 4 in x 5 in x 1/4 in deep (10.2 cm x 12.7 cm x 0.6 cm deep) on the passenger side and 7 in x 13 in x 1/2 in deep (17.8 cm x 33.0 cm x 1.3 cm deep) on the driver side. The floorpan was pushed inward toward the occupant compartment a distance of 2 in. (5.1 cm) and the steering wheel was bent. There was also damage to the front bumper, hood, grill, radiator, the left front strut, left front quarter panel, right front quarter panel, and the left front tire and rim.

The vehicle did not lose contact with the guardrail but came to rest on top of the rail and posts. Data from the accelerometer located at the center-of-gravity were digitized for evaluation and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 41.8 ft/sec (12.7 m/sec) at 0.103 sec, the highest 0.010-second average ridedown acceleration was -12.8 g between 0.104 and 0.114 sec, and the maximum 0.050-second average acceleration was -16.3 g between 0.031 and 0.081 sec. In the lateral direction, occupant impact velocity was 10.7 ft/sec (5.5 m/sec) at 0.251 sec, the highest 0.010-second occupant ridedown acceleration was 2.5 g between 0.254 and 0.264 sec, and the maximum 0.050-second average acceleration was 5.0 g between 0.084 and 0.134 sec. This data and other pertinent information from the test are summarized in Figure F-17. Vehicular angular displacements are displayed in Figure F-19, and vehicular acceleration versus time traces, filtered at SAE J211 (Class 180), are presented in Figures F-19 through F-21.

Since the longitudinal occupant impact velocity exceeded the maximum allowable limit of 40 ft/sec (12.2 m/sec) specified in NCHRP Report 230, this test was considered a failure.

Test 1263-2 (1,800 lb/59.0 mph/20.4 deg)

Based on the results of test 1, the short radius system was modified to improve its impact performance with the small car. To facilitate fracture of the weakened posts along the curved segment of rail, the embedment of the CRT posts was increased from 38 in. to 44 in. In

Table F-1. Rail Movement During Test 1263-1

Time (sec)	Post 7	Post 8	Post 9	Post 10
0.025	fwd 0.218	fwd 0.102	0.707	0.000
0.049	fwd 0.738	0.442	2.500	0.229
0.074	0.432	1.287	3.565	0.345
0.098	origin	2.529	4.455	0.358
0.123	origin	3.477	5.316	0.519
0.148	origin	4.409	6.335	0.559
0.172	0.125	5.322	7.033	0.636
0.197	0.443	5.833	7.299	0.702
0.221	0.918	6.332	7.428	0.718
0.246	1.407	6.432	7.964	0.764
0.271	1.861	6.758	8.091	0.768
0.295	2.467	7.199	8.562	0.770
0.320	2.959	7.244	9.158	0.749
0.345	3.340	7.483	9.275	0.680
0.369	3.752	7.681	9.376	0.674
0.394	4.057	7.759	9.712	0.702
0.418	4.135	7.923	9.466	0.677
0.443	4.117	7.879	9.403	0.692
0.468	4.172	7.867	9.553	0.732
0.492	4.117	7.923	9.404	0.743

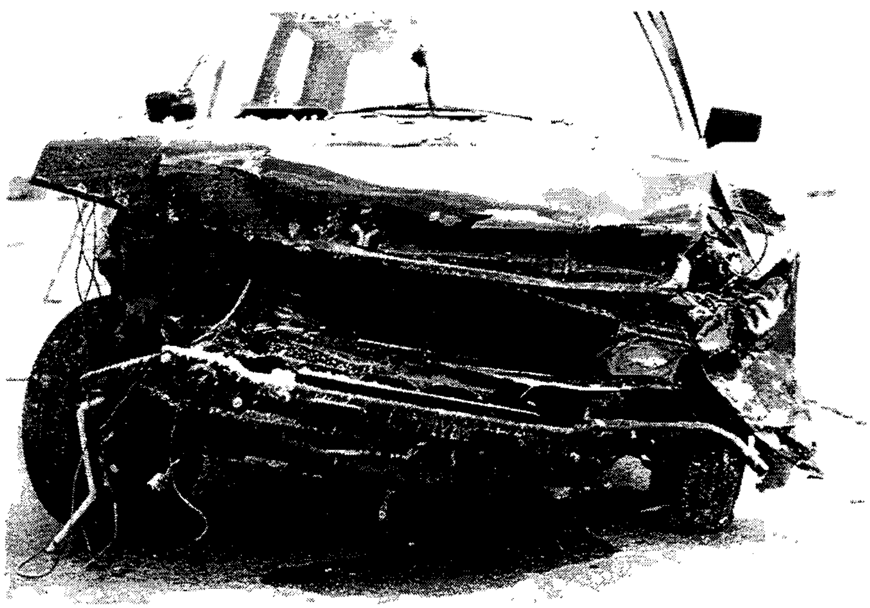


FIGURE F-15. Vehicle after Test 1263-1

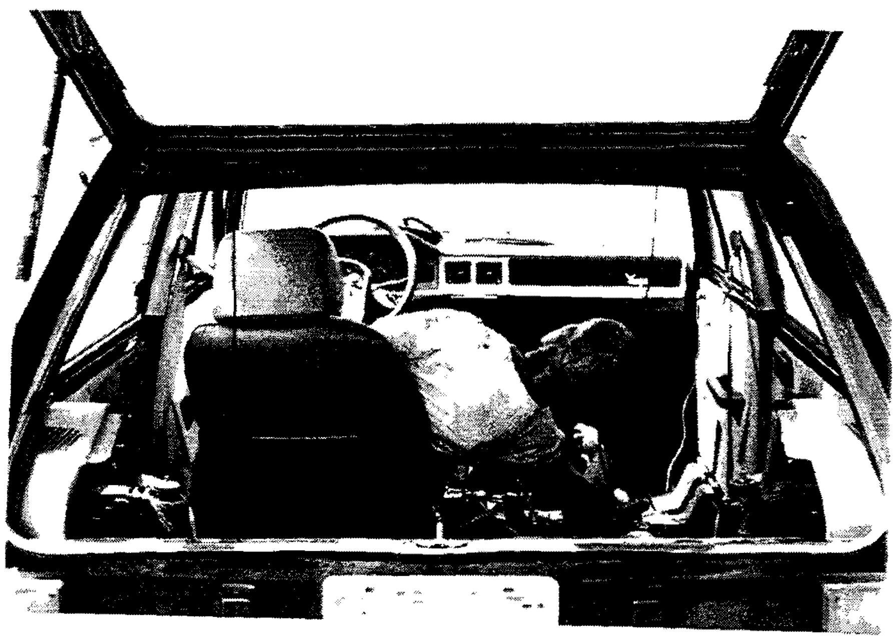
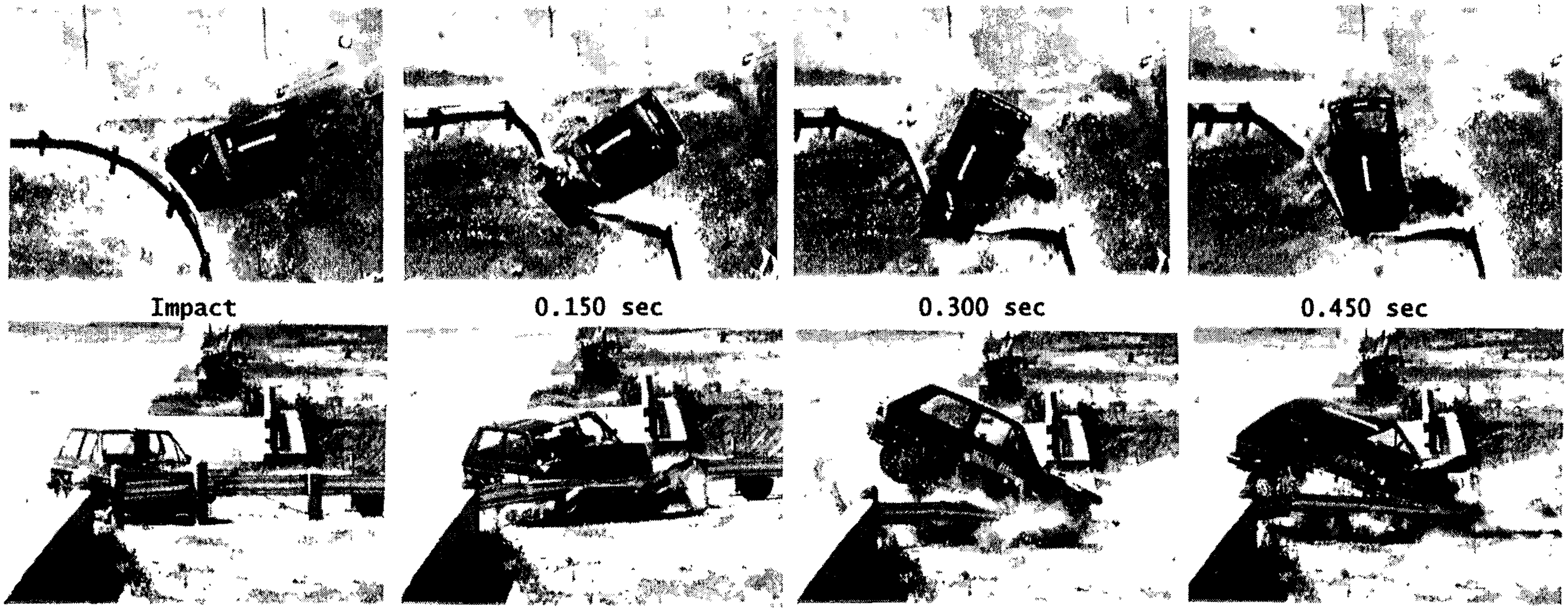


FIGURE F-16. Anthropometric Dummy after Test 1263-1



Test No.	1263-1
Date	07/29/92
Test Installation . . .	Short-Radius Guardrail Treatment
Installation Length . .	100 ft (30 m)
Max. Dynamic Movement .	9.7 ft (3.0 m)
Max. Perm. Movement . .	6.0 ft (1.8 m)
Test Vehicle.	1987 Yugo GV
Vehicle Weight	
Test Inertia	1,800 lb (817 kg)
Gross Static	1,970 lb (894 kg)
Vehicle Damage Classification	
TAD	12FD6
CDC	12FDEW3
Maximum Vehicle Crush. .	15.5 in (39.4 cm)

Impact Speed.	58.4 mi/h (94.0 km/h)
Impact Angle.	20.5 deg
Speed at Parallel . .	N/A
Exit Speed	Vehicle landed on rail
Exit Trajectory . . .	N/A
Vehicle Accelerations at center-of-gravity (Max. 0.050-sec Average)	
Longitudinal. . . .	-16.3 g
Lateral	5.0 g
Occupant Impact Velocity at true c.g.	
Longitudinal. . . .	41.8 ft/s (12.7 m/s)
Lateral	10.7 ft/s (3.3 m/s)
Occupant Ridedown Accelerations	
Longitudinal . . .	-12.8 g
Lateral	2.5 g

FIGURE F-17. Summary of Results for Test 1263-1

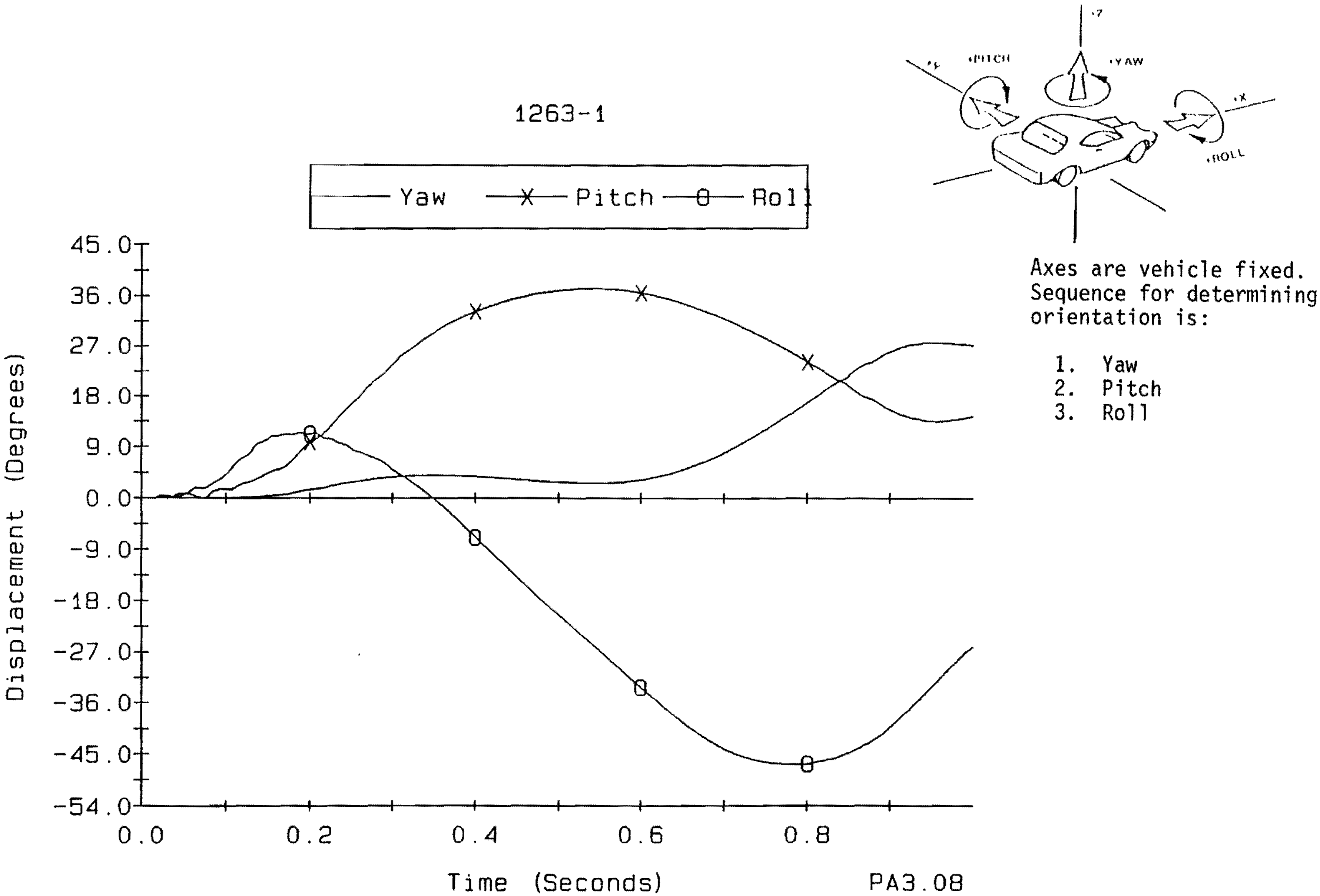


FIGURE F-18. Vehicular Angular Displacement for Test 1263-1

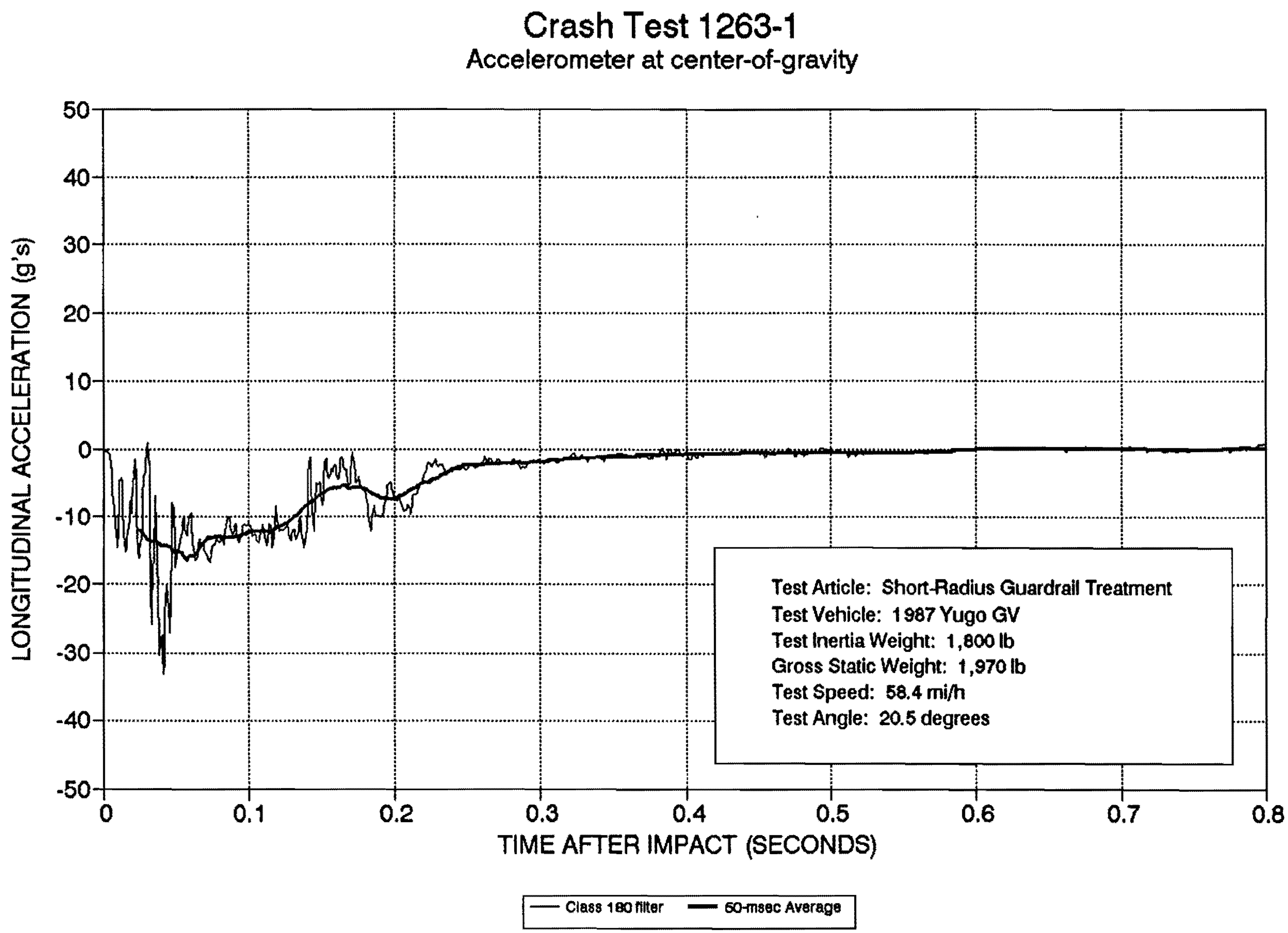


FIGURE F-19. Longitudinal Accelerometer Trace for Test 1263-1

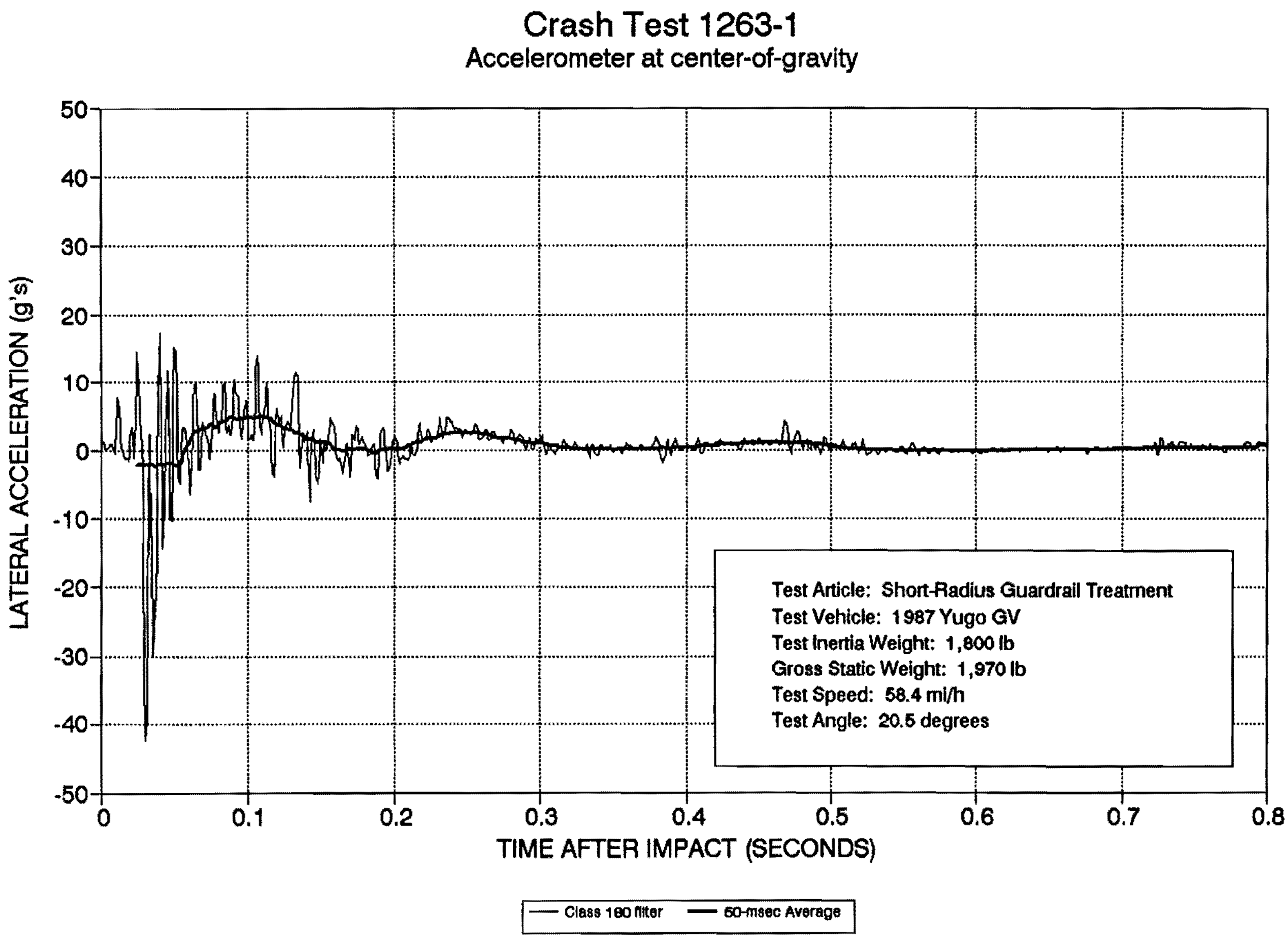


FIGURE F-20. Lateral Accelerometer Trace for Test 1263-1

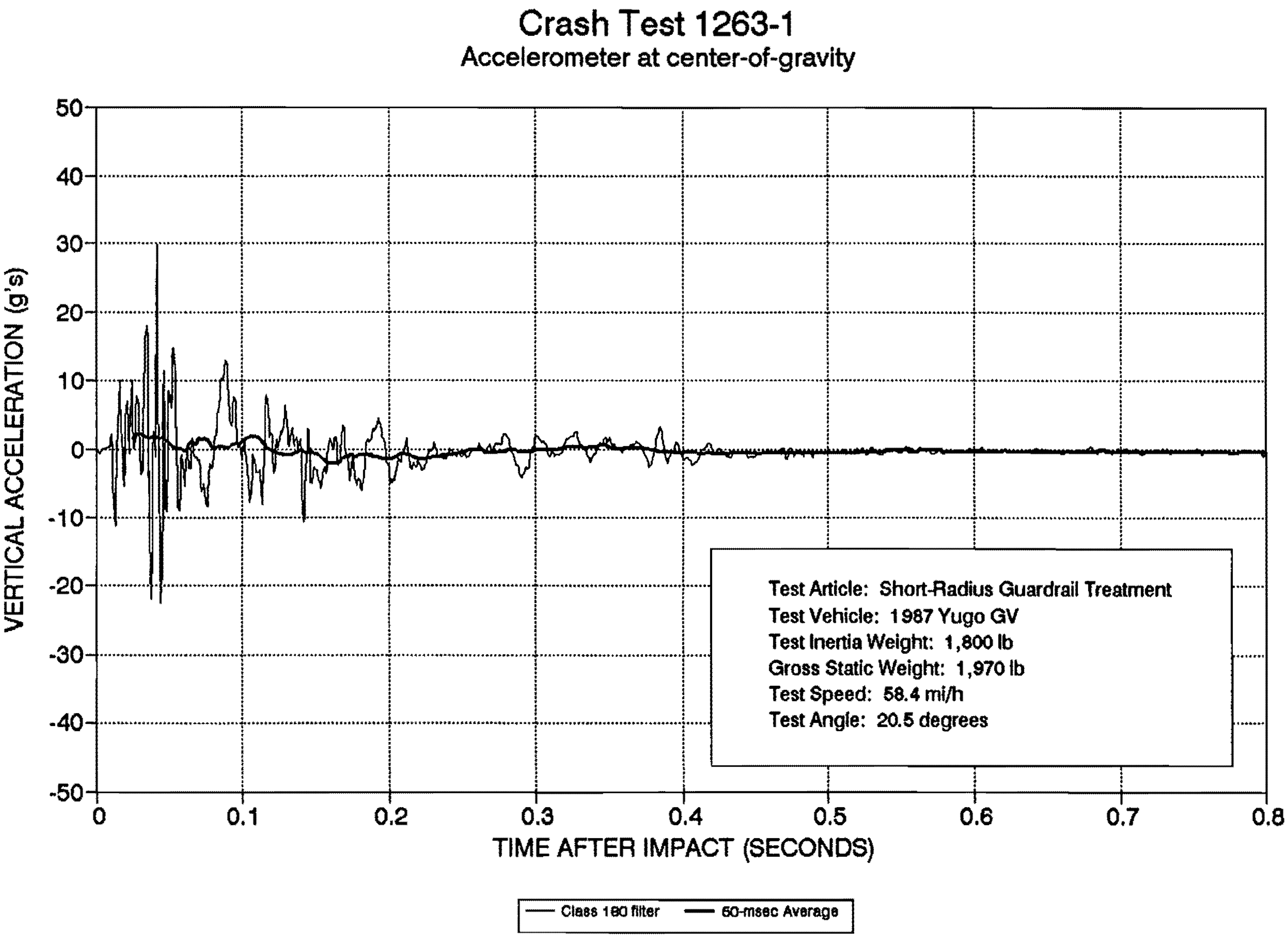


FIGURE F-21. Vertical Accelerometer Trace for Test 1263-1

addition, the in-line anchor in the curved section of rail was eliminated due to its adverse effect on test 1. After making these modifications, test 1 was repeated with a 1987 Yugo GV (Figure F-22) to reevaluate the system's impact performance for headon impacts with a small car. The modified short radius system which was evaluated in this test is shown in Figures F-23 and F-24. Test inertia mass of the vehicle was 1,800 lb (817 kg) and its gross static mass was 1,970 lb (894 kg). The bumper height of the vehicle ranged from 13.25 in. (33.7 cm) at its lower edge to 18.5 in. (47.0 cm) at its upper edge. Additional dimensions and information on the test vehicle are given in Figure F-25. The vehicle was directed into the guardrail as shown in Figure F-26 using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the guardrail travelling at a speed of 59.0 mi/h (94.9 km/h) and at an angle of 20.4 degrees.

Shortly after impact, posts 8 and 9 fractured at the ground line and the system appeared to be working as designed. As the vehicle continued to deflect the rail, movement was observed at posts 7 and 10. Shortly thereafter, approximately 0.142 sec after impact, the W-beam rail element unexpectedly tore at a splice connection, permitting the test vehicle to penetrate through the rail. The brakes on the vehicle were activated at 1.2 sec after impact and the vehicle subsequently came to rest behind the guardrail installation. Sequential photographs are shown in Figures F-27 and F-28.

As can be seen in Figures F-29 through F-31, the guardrail received considerable damage. The rail element experienced a complete tear at the outside splice bolt holes near post 8. The rail was wrapped around post 7 which was displaced approximately 2 in. (5 cm) at the ground line. CRT posts 8 and 9 were fractured at ground level, and post 10 was displaced rearward 8 in. (20 cm). Measurement of the movement of the rail element at posts 7 through 10 were taken and reported for specific times as noted in Table F-2.

Since the rupture of a W-beam is so uncommon for a small car impact, test coupons were cut from the rail at two different locations near the tear and sent to an independent laboratory for testing. The purpose of the tests was to determine whether or not the strength and ductility of the rail were within AASHTO specification M-180-74 (11). These specifications require a yield strength of 50 ksi, a tensile strength of 70 ksi, and a 12% ductility at 2% elongation. The results of the laboratory tests are shown in Table F-3. Although significant variations within the

FIGURE F-22. Vehicle Prior to Test 1263-2

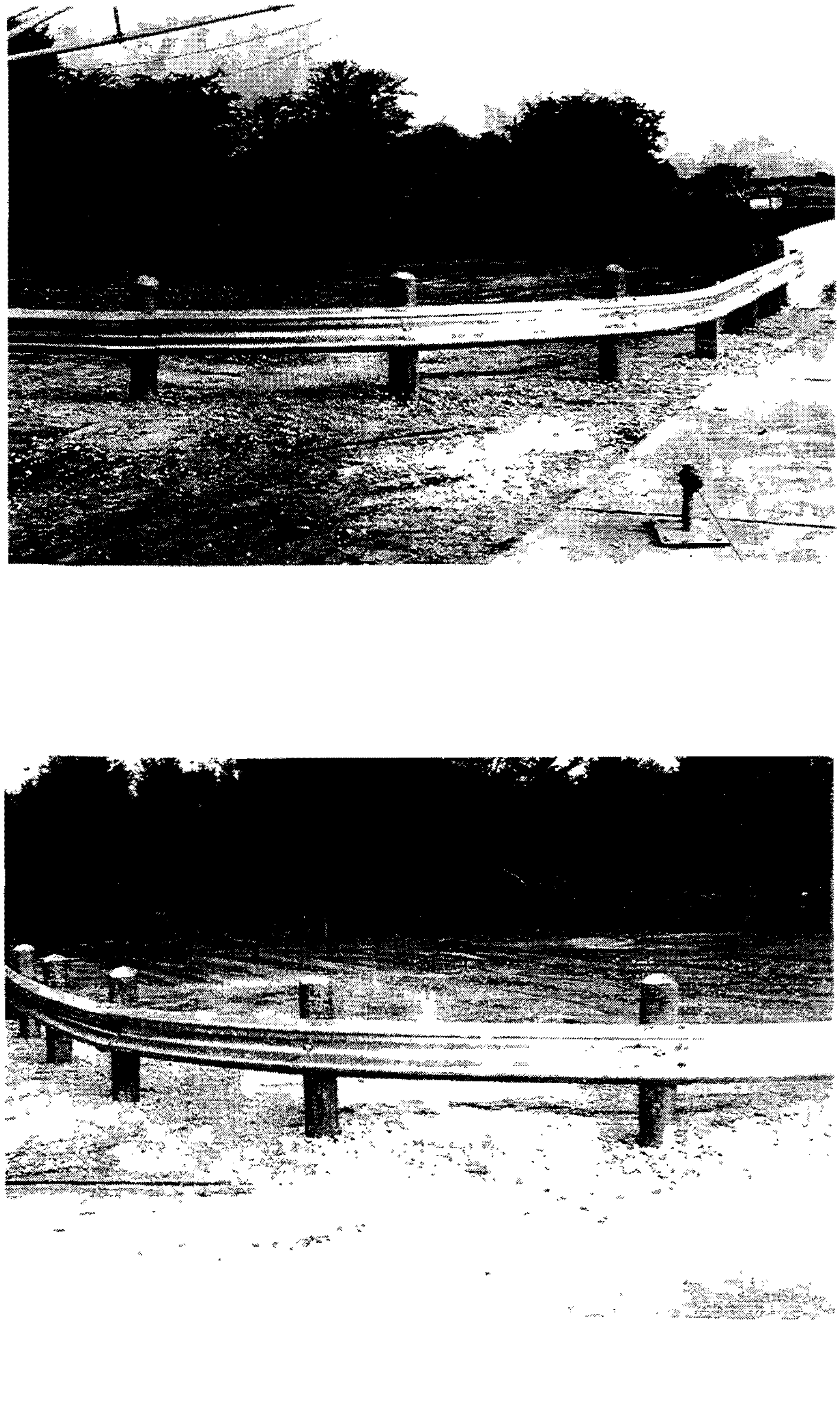


FIGURE F-23. Short Radius Guardrail Treatment before Test 1263-2

FIGURE F-24. **Short Radius Guardrail Treatment before Test 1263-2 (Rear View)**

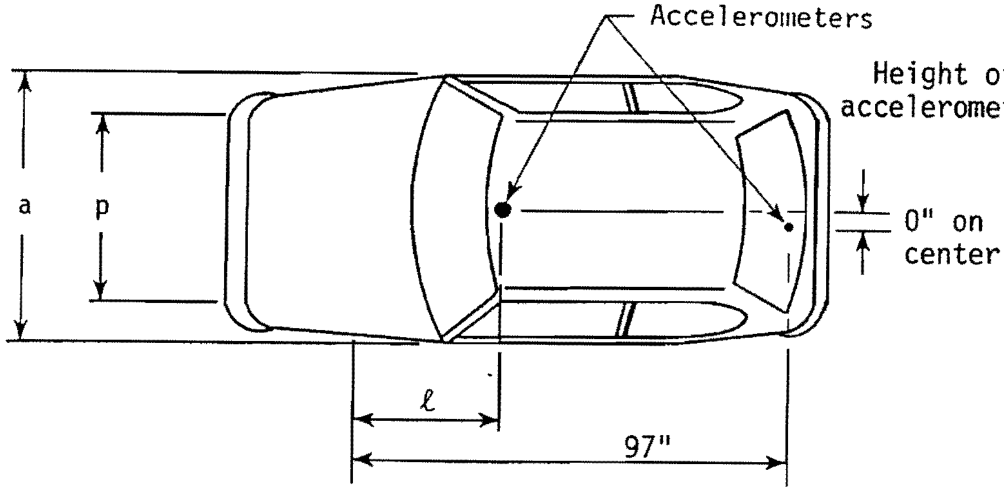
Date: 8-7-92 Test No.: 1263-2 VIN: VX1BA1213HK360320

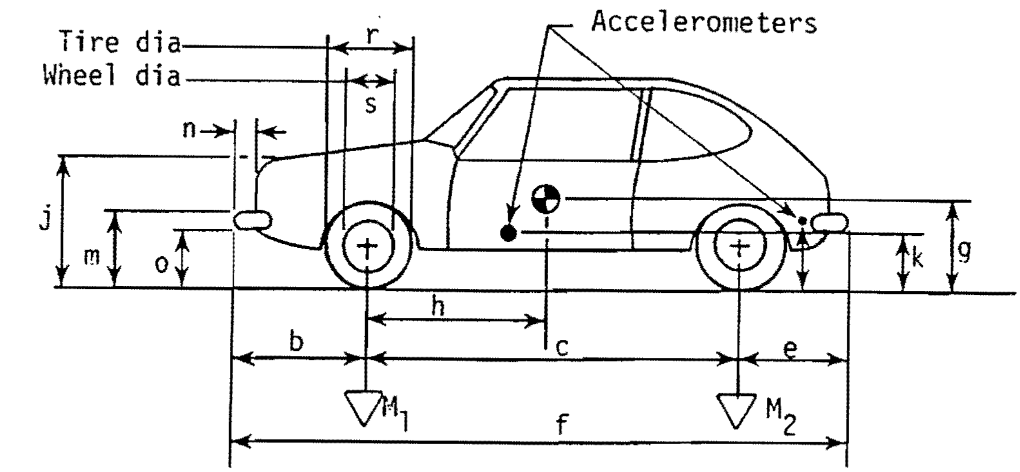
Make: Yugo Model: GV Year: 1987 Odometer: 72655

Tire Size: ______ Ply Rating: ______ Bias Ply: __ Belted: __ Radial: X

Tire Condition: good __ fair X badly worn __

Height of rear accelerometer: 27"





Vehicle Geometry - inches

a	60.25"	b	26.25"
c	85"	d*	55"
e	24"	f	135.25"
g		h	31.7"
i	----	j	30.75"
k	15.25"	ℓ	31"
m	18.5"	n	2.75"
o	13.25"	p	52.5"
r	22.25"	s	14.25"

4-wheel weight for c.g. det. ℓf 562 rf 567 ℓr 328 rr 343

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1182	1129	1208
M_2	607	671	762
M_T	1789	1800	1970

Note any damage to vehicle prior to test:

Crack in windshield)marked).

Engine Type: 4 cyl

Engine CID: 1100 cc

Transmission Type:

XXXXXXXXXXXXXX Manual

FWD XXXXXXXXXXXXXX

Body Type: Hatch

Steering Column Collapse Mechanism:

__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:

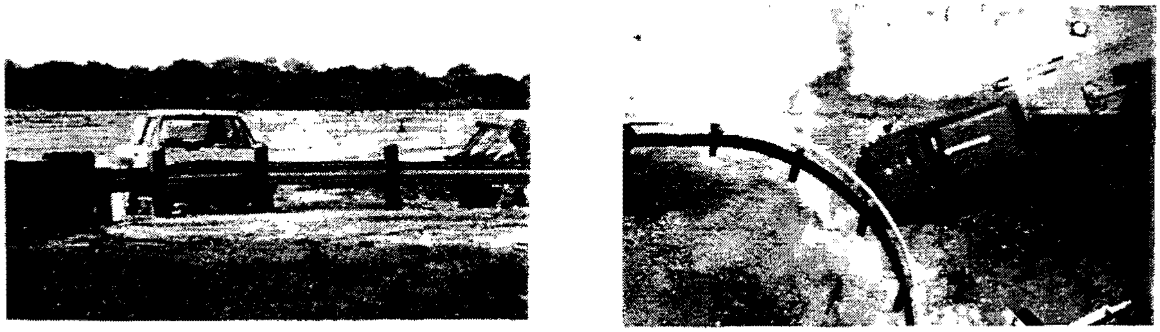
Front: disc X drum __

Rear: disc __ drum X

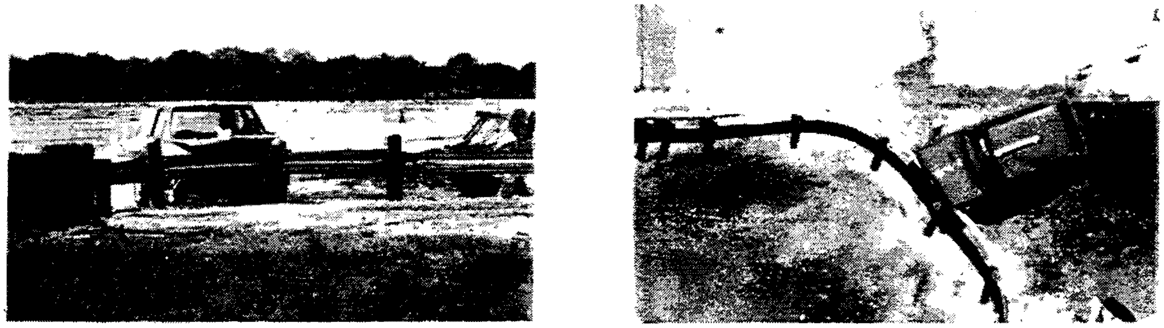
*d = overall height of vehicle

FIGURE F-25. Test Vehicle Properties (1263-2)

FIGURE F-26. Vehicle/Guardrail Geometrics for Test 1263-2



0.000 s

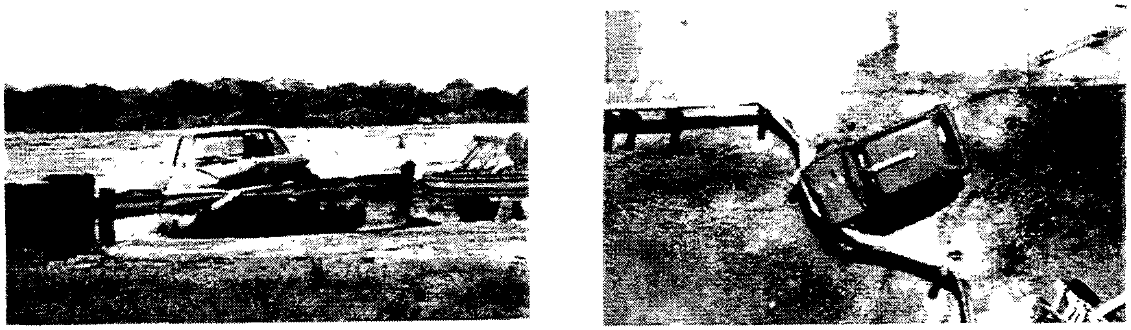


0.030 s

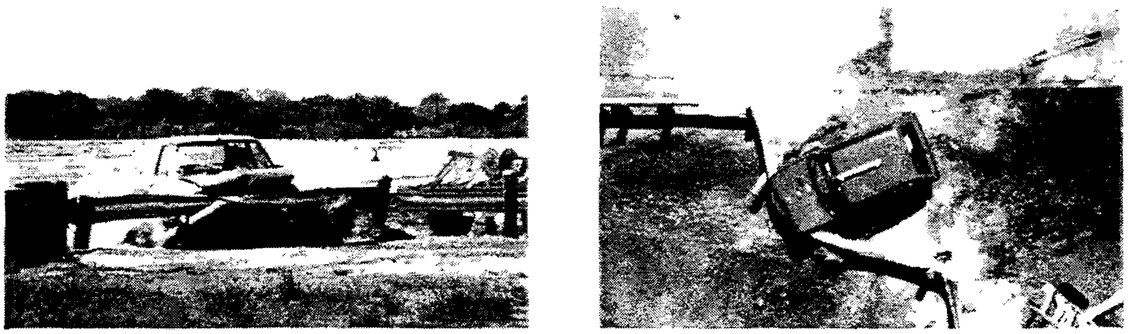
0.059 s

0.089 s

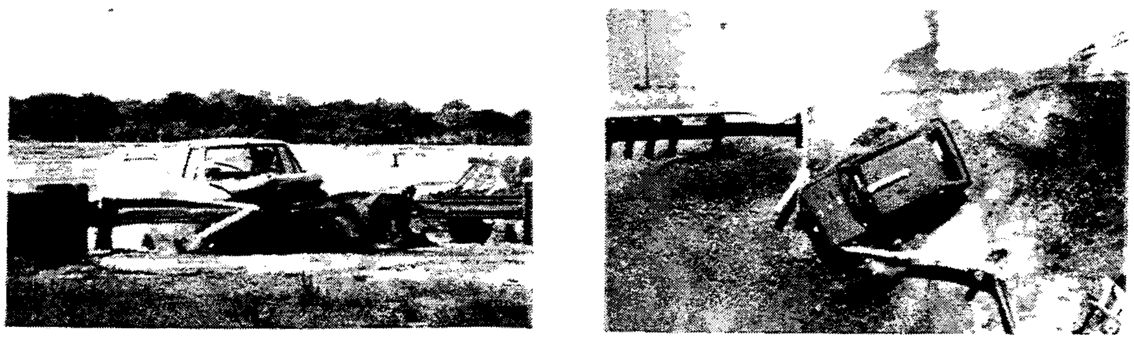
FIGURE F-27. Sequential Photographs for Test 1263-2 (Frontal and Overhead Views)



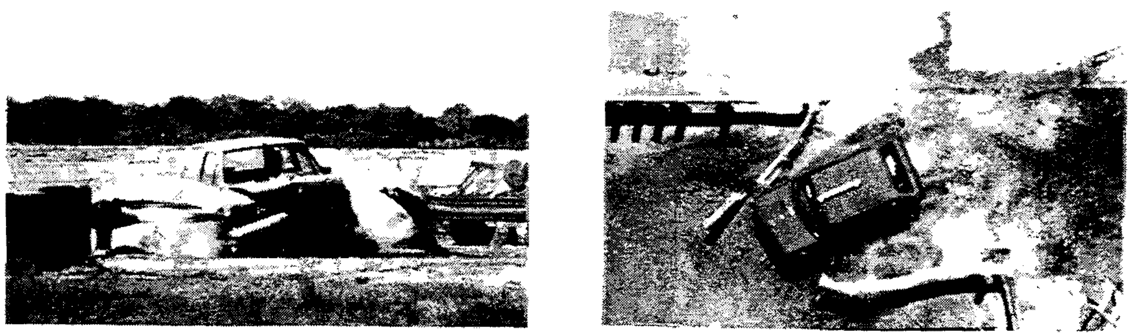
0.118 s



0.148 s

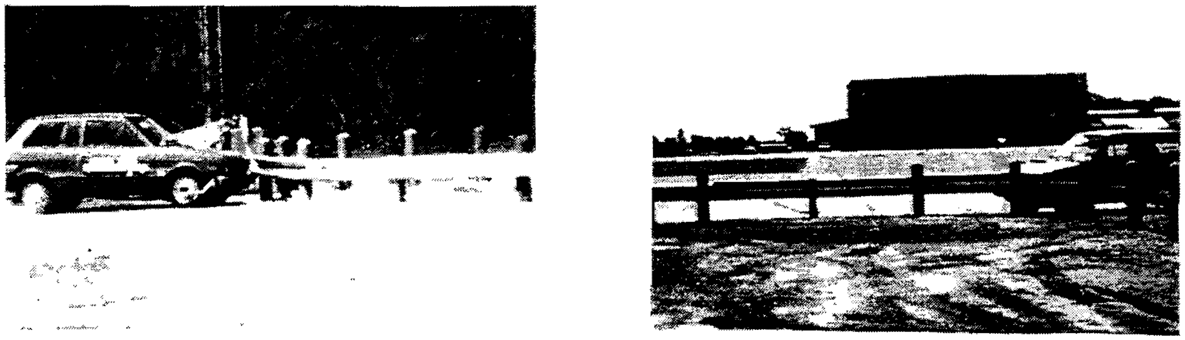


0.177 s



0.251 s

FIGURE F-27. Sequential Photogrpahs for Test 1263-2 (Frontal and Overhead Views) (continued)



0.000 s

0.030 s

0.059 s

0.089 s

FIGURE F-28. Sequential Photographs for Test 1263-2 (Side Views)

0.118 s

0.148 s

0.177 s

0.251 s

FIGURE F-28. Sequential Photographs for Test 1263-2 (Side Views) (continued)

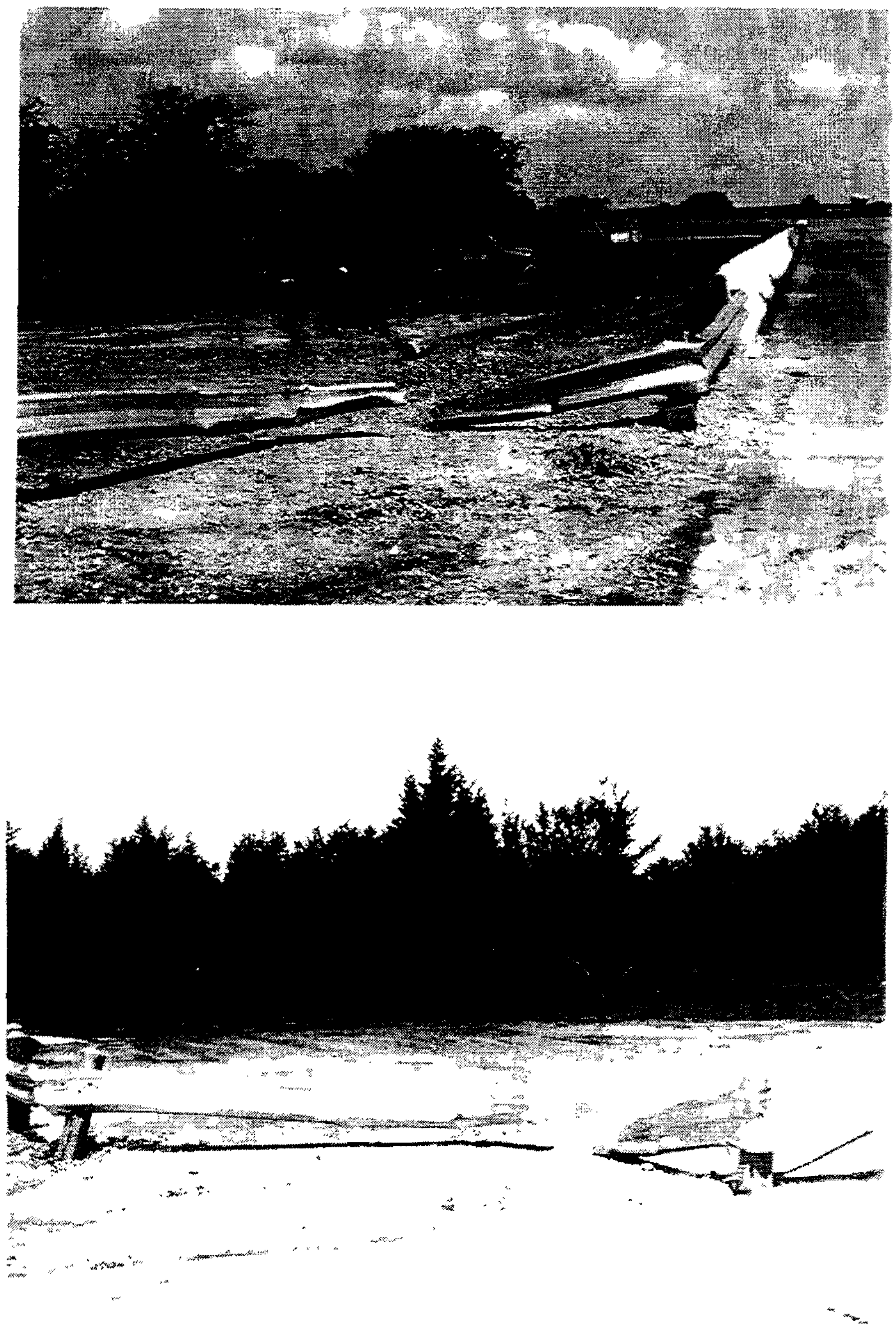
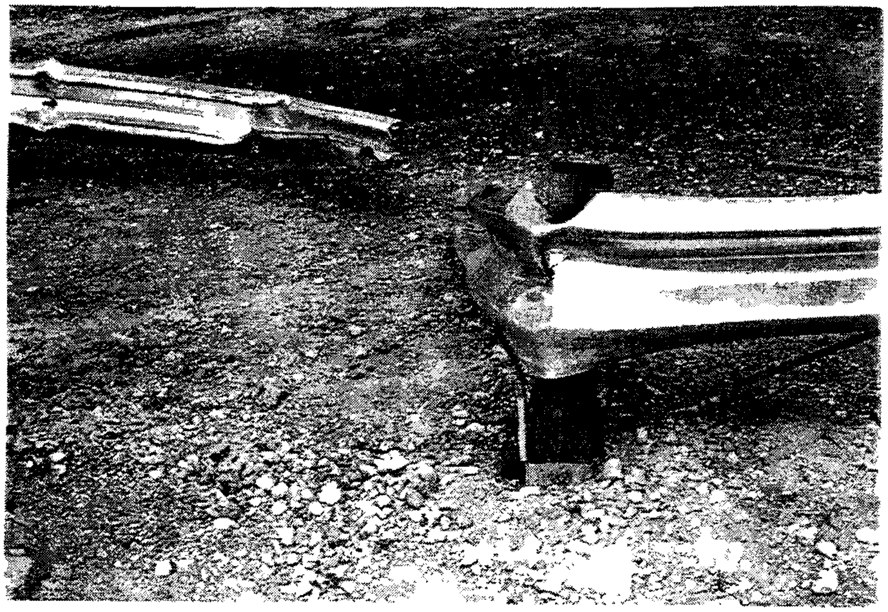


FIGURE F-29. Test Site after Test 1263-2



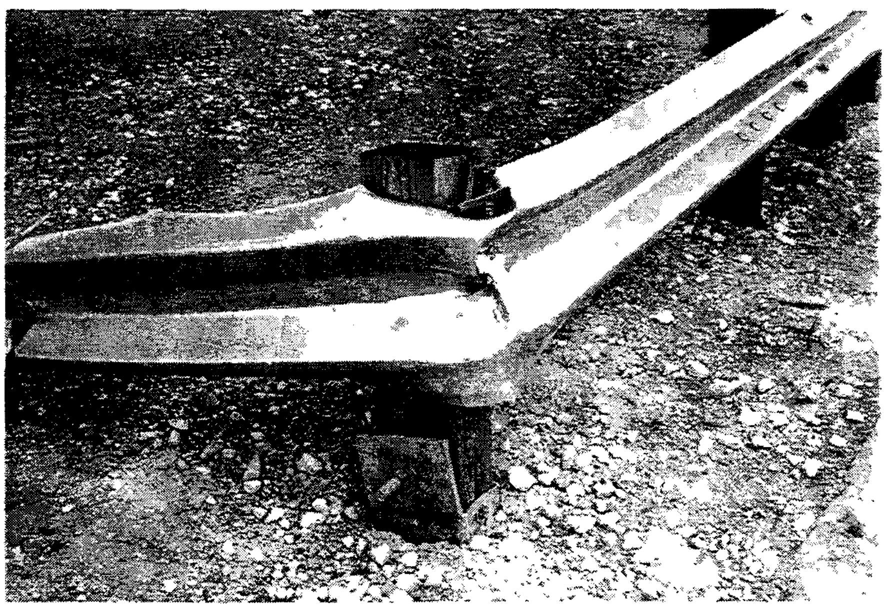


FIGURE F-30. Damage at Post 7, Test 1263-2

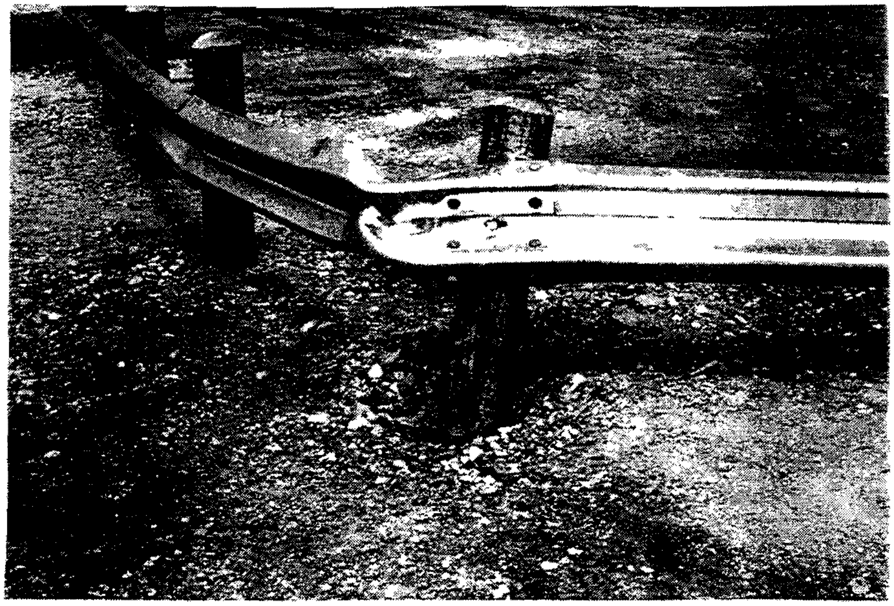


FIGURE F-31. Damage at Post 10, Test 1263-2

TABLE F-2. Rail Movement During Test 1263-2

Time (sec)	Post 7	Post 8	Post 9	Post 10
0.025	fwd 0.239	fwd 0.073	0.894	0
0.049	fwd 0.676	0.597	2.580	0.189
0.074	0.130	1.646	4.202	0.500
0.098	origin	3.364	5.784	0.802
0.123	origin	5.048	7.095	1.277
0.148	0.324	7.371	7.496	1.265
0.172	0.593	8.841	7.779	1.838
0.197	0.425	10.340	8.083	2.032
0.221	0.457	11.637	8.606	1.809
0.246	0.425	12.740	9.159	2.005

TABLE F-3. Laboratory Analysis of Fractured W-Beam Rail

AUG-12-'92 TUE 13:20 ID: SWL-HOUSTON TEL NO:713 696-6307 #924 P02

SwL **SOUTHWESTERN LABORATORIES**

Materials, environmental and geotechnical engineering, nondestructive, metallurgical and analytical services

222 Cavalcade St. • P.O. Box 8768, Houston, Texas 77249 • 713/692-9151

REPORT OF ANALYSIS AND TESTS

Attn: Dr. Ross
Client: Texas A + M

Report No. 59068-1
File No.
Report Date
P. O. No.

Project: Mechanical Testing

PROJECT INFORMATION

Material-Size & Type: One (1) Sample Section of Rail
Identification: 1263-1
Date Sample Received: 8-10-92
Date of Test: 8-11-92
Specification: N/A
Test Performed By: MP
Test Equipment: Satec 1195
Test Procedure: ASTM A370

TEST RESULTS

TENSILE TEST

Specimen Identification	Specimen Dimensions	Area, Sq. Ins.	Yield Strength p.s.i.*	Total Load, Pounds	Tensile Strength p.s.i.	% E. (2)	% R.A.	Young's Modulus
59068-1T Tension Side	0.500 0.108	0.0540	75,800	4715	87,300	16	N/A	22.7 X 10^6
59068-1C Compression Side	0.496 0.106	0.0526	62,600	4120	78,300	26	N/A	27.6 X 10^6

*Yield Strength Was Determined At 0.2% offset

TABLE F-3. Laboratory Analysis of Fractured W-Beam Rail (continued)

AUG-12-'92 TUE 13:21 ID: SWL-HOUSTON TEL NO:713 696-6307 #924 P03

SWL **SOUTHWESTERN LABORATORIES**

Materials, environmental and geotechnical engineering, nondestructive, metallurgical and analytical services

222 Cavalcade St. • P.O. Box 8768, Houston, Texas 77249 • 713/892-9151

REPORT OF ANALYSIS AND TESTS

Attn:
Client: Texas A&M

Report No. 59068-2
File No.
Report Date
P. O. No.

Project:

PROJECT INFORMATION

Material-Size & Type: One (1) Sample Section of Rail
Identification: 1263-2
Date Sample Received: Same
Specification:
Test Equipment:
Date of Test:
Test Performed By:
Test Procedure:

TEST RESULTS

TENSILE TEST

Specimen Identification	Specimen Dimensions	Area, Sq. Ins.	Yield Strength p.s.i.*	Total Load, Pounds	Tensile Strength, p.s.i.	% E, ( )	% R.A.	Youngs Modulus
59068-3 T Tension Side	0.499 0.103	0.0514	80,500	4626	90,000	17	n/a	23.9×10^6
59068-3 C Compression Side	0.496 0.104	0.0516	65,200	4057	78,600	28	n/a	26.1×10^6

*Yield Strength Was Determined At 0.2% offset rail are evident, the results of the tensile tests all exceed the minimum requirements for guardrail.

Damage sustained by the test vehicle is shown in Figure F-32. Maximum recorded crush at bumper height was 12.0 in. (30.5 cm) and 8.0 in. (20.3 cm) at the left and right front corners of the vehicle, respectively. The driver's side wheel was pushed rearward 4.0 in. (10.2 cm). The driver's door was deformed outward 1.0 in. (2.5 cm), and the driver's side window was broken out. There was a dent in the roof above the rear passenger compartment on the driver's side which measured 9 in x 14 in x 1/4 in deep (22.9 cm x 35.6 cm x 0.6 cm deep). In addition, there was damage to the front bumper, hood, grill, radiator, fan, the left and right front struts, the left and right front quarter panels, and the left and right doors.

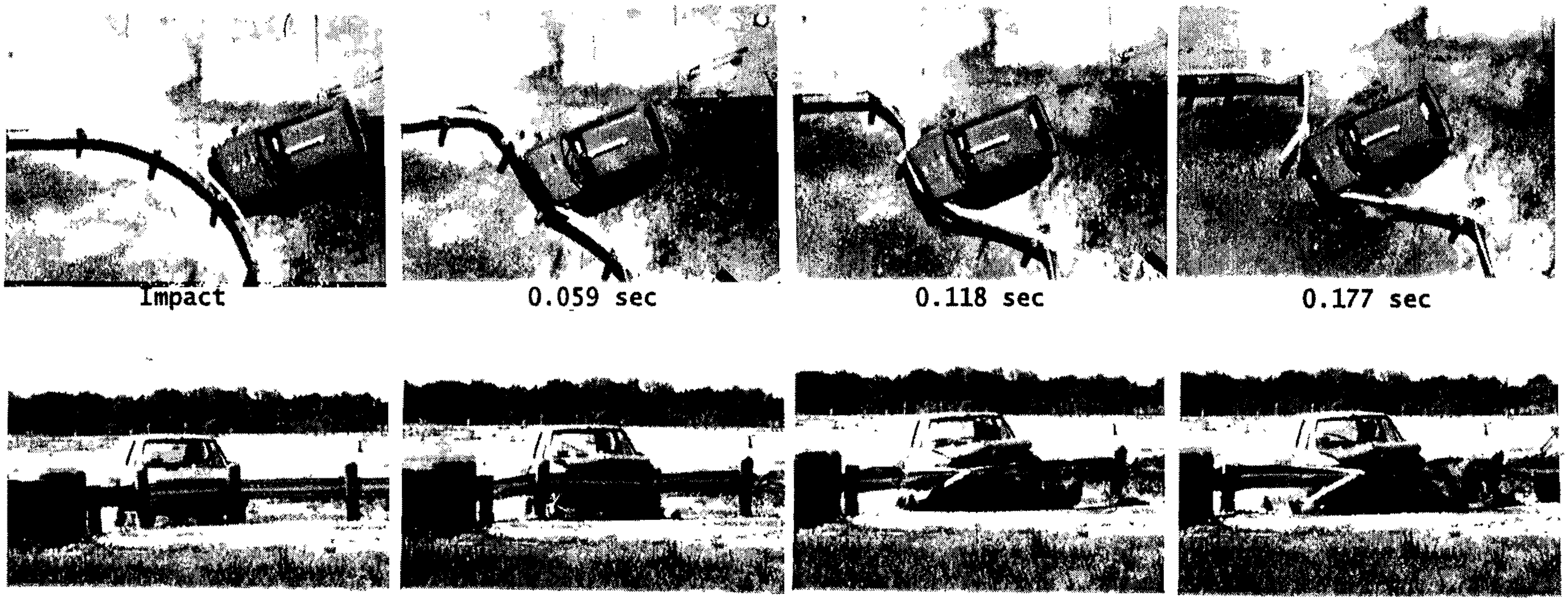
The vehicle penetrated through the guardrail while travelling at a speed of 35.8 mi/h (57.6 km/h). Data from the accelerometer located at the center-of-gravity were digitized for evaluation and occupant risk factors were computed. In the longitudinal direction, occupant impact velocity was 27.4 ft/sec (8.3 m/sec) at 0.129 sec, the highest 0.010-second average ridedown acceleration was -10.5 g between 0.153 and 0.163 sec, and the maximum 0.050-second average acceleration was -9.9 g between 0.005 and 0.055 sec. In the lateral direction, occupant impact velocity was 4.2 ft/sec (1.3 m/sec) at 0.696 sec, the highest 0.010-second average ridedown acceleration was 0.8 g between 0.742 and 0.752 sec, and the maximum 0.050-second average acceleration was 2.2 g between 0.077 and 0.127 sec. The change in vehicle velocity at loss of contact with the guardrail (at 0.153 sec) was 23.2 mi/h (37.3 km/h). This data and other pertinent information from the test are summarized in Figure F-33. Vehicular angular displacements are displayed in Figure F-34, and vehicular accelerations plotted versus time are presented in Figures F-35 through F-37.

Since the vehicle penetrated through the guardrail and was not contained, this test was considered to be a failure as per evaluation criteria A of NCHRP Report 230.

Test 1263-3 (1,800 lb/60.2 mph/20 deg/)

In an effort to eliminate the rail fracture observed in the previous test, the strength of the rail was doubled by incorporating a nested W-beam around the curve. The small car test was then repeated using the same impact conditions of the previous two tests. A 1987 Yugo GV, shown in Figures F-38 and F-39, was used as the test vehicle. The modified short radius system

FIGURE F-32. Vehicle after Test 1263-2



Test No. 1263-2
Date 08/07/92
Test Installation . . . Short-Radius Guardrail Treatment
Installation Length . . 100 ft (30 m)
Max. Dynamic Movement . Rail separated
Max. Perm. Movement . . Rail separated
Test Vehicle . . . . . . 1987 Yugo GV
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . 1,970 lb (894 kg)
Vehicle Damage Classification
  TAD 12FD5
  CDC 12FDEW3
Maximum Vehicle Crush. . 12.0 in (30.5 cm)

Impact Speed. . . . . 59.0 mi/h (94.9 km/h)
Impact Angle. . . . . 20.4 deg
Speed at Parallel . . N/A
Exit Speed . . . . . 35.8 mi/h (57.6 km/h)
Exit Trajectory . . . exited behind the rail
Vehicle Accelerations at center-of-gravity
 (Max. 0.050-sec Average)
  Longitudinal. . . . -9.9 g
  Lateral . . . . . . 2.2 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . 27.4 ft/s (8.4 m/s)
  Lateral . . . . . . 4.2 ft/s (1.3 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . . -10.5 g
  Lateral . . . . . . 0.8 g

FIGURE F-33. Summary of Results for Test 1263-2

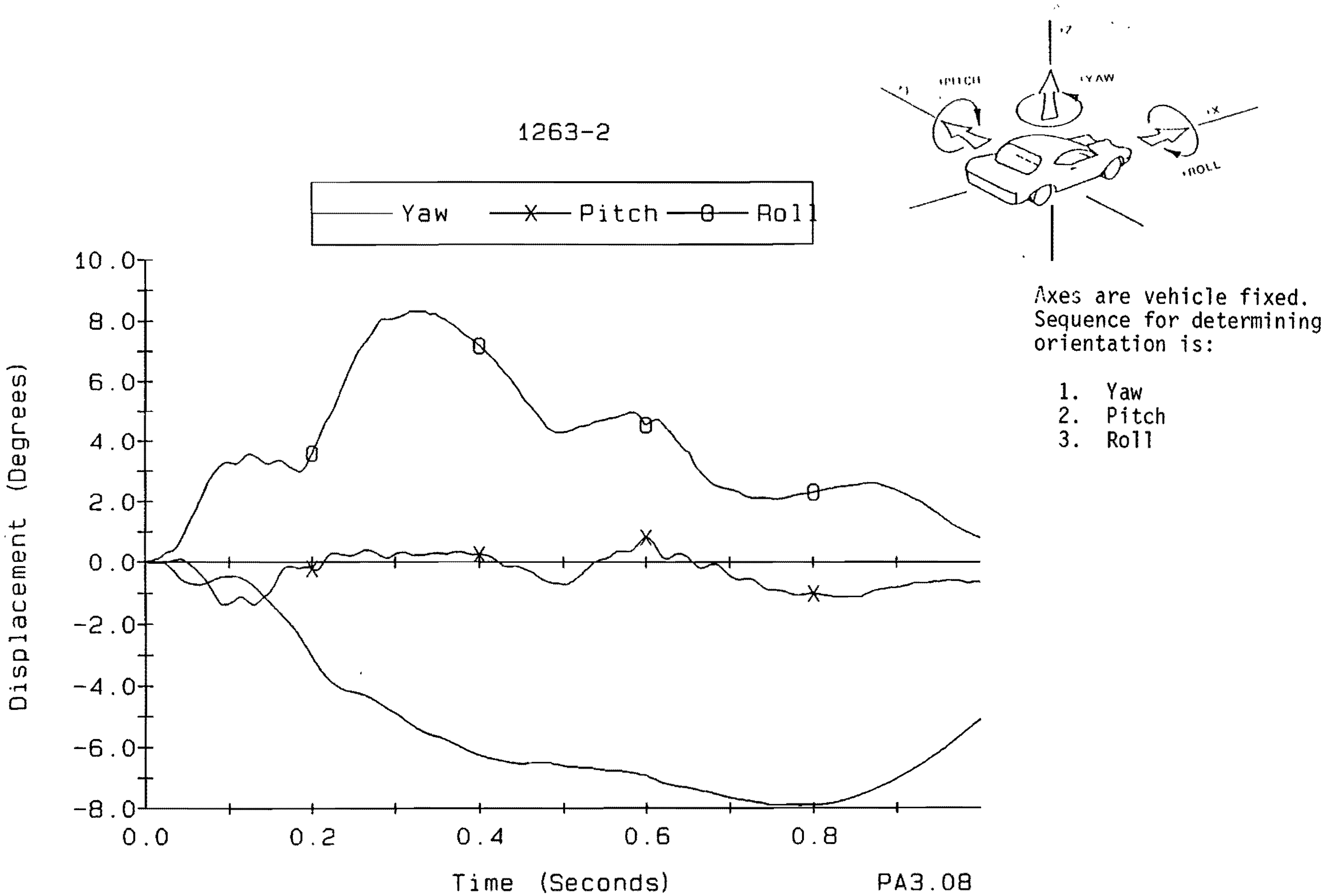


FIGURE F-34. Vehicle Angular Displacement for Test 1263-2

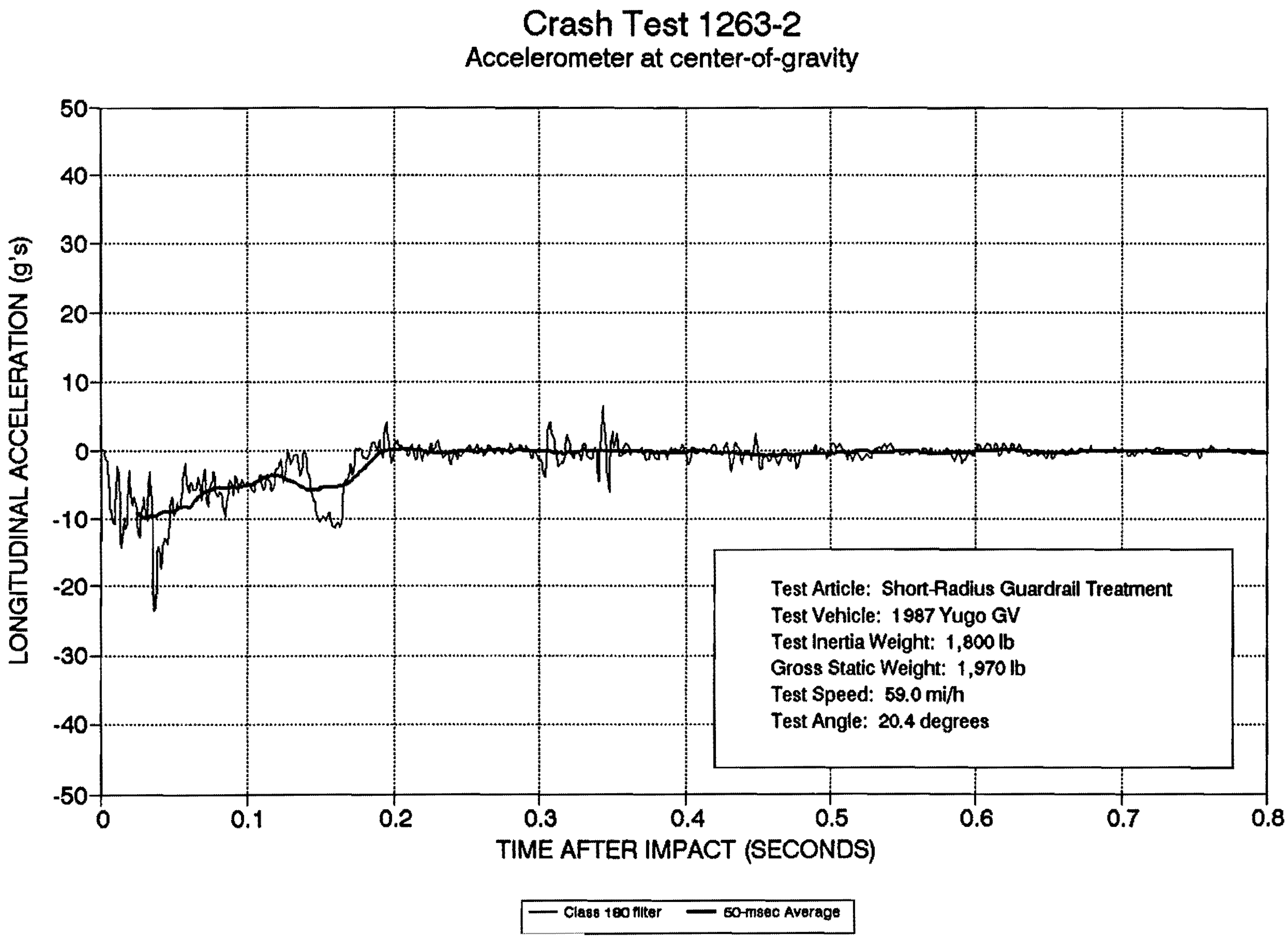


FIGURE F-35. Longitudinal Accelerometer Trace for Test 1263-2

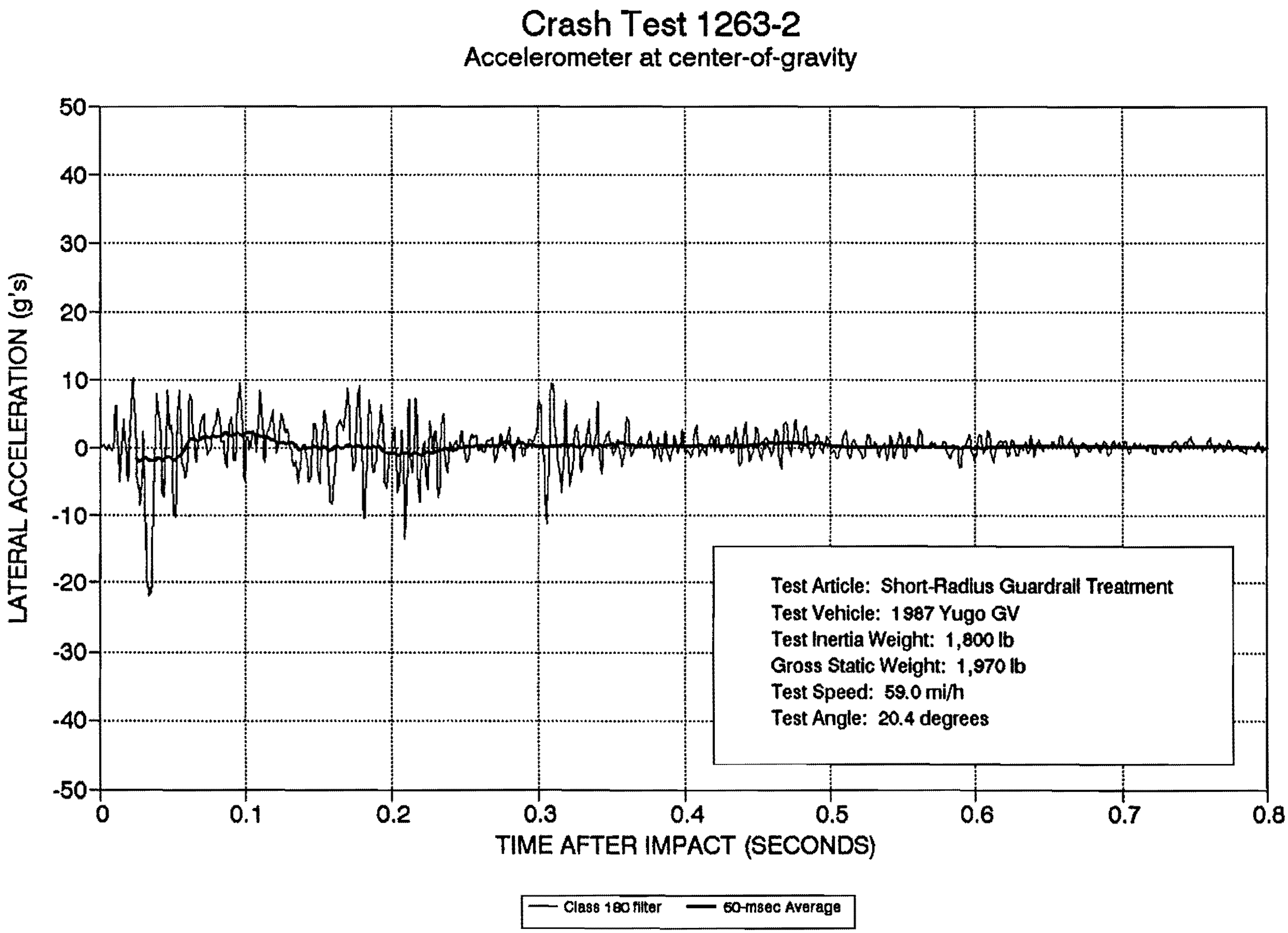


FIGURE F-36. Lateral Accelerometer Trace for Test 1263-2

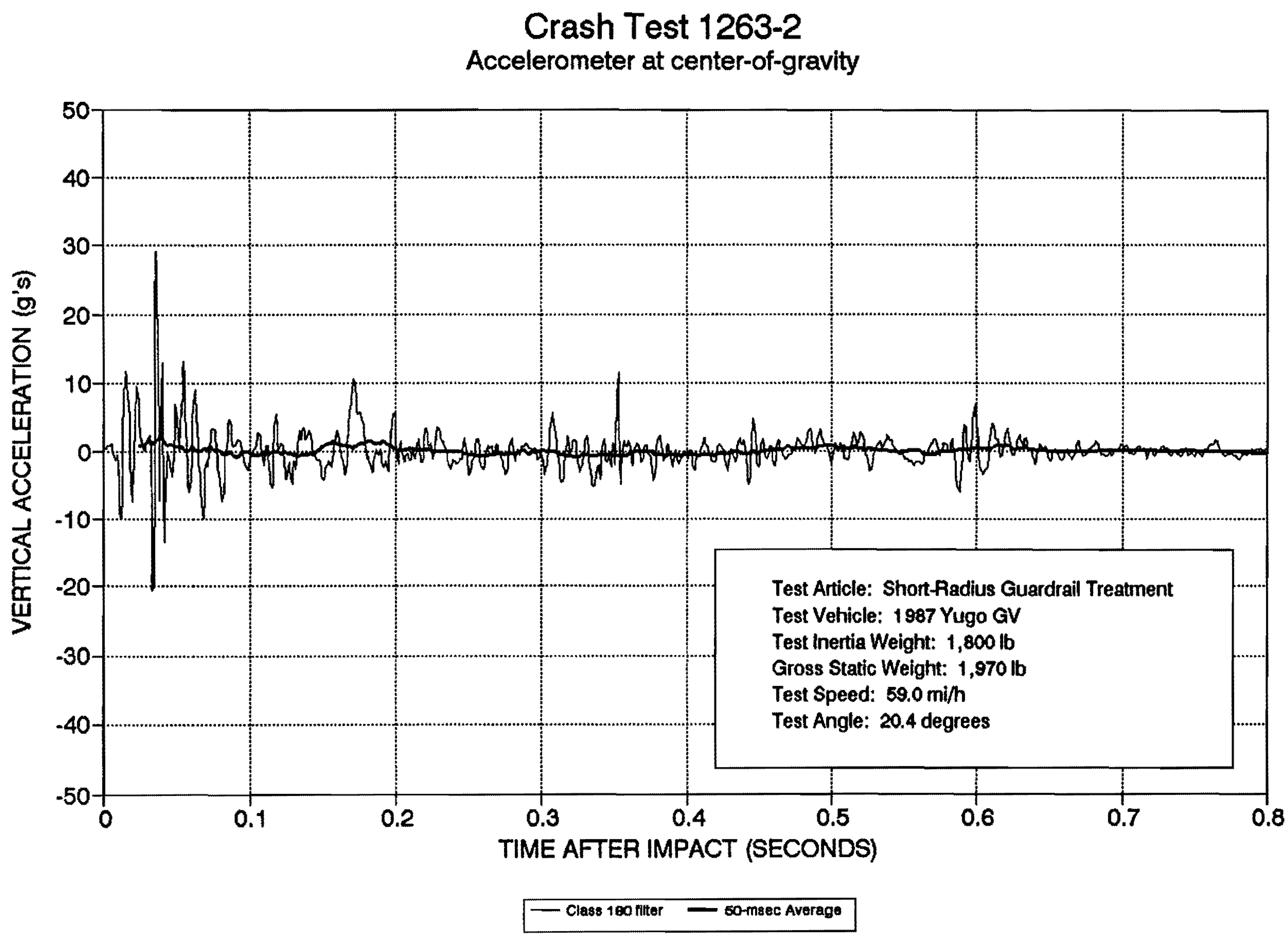


FIGURE F-37. Vertical Accelerometer Trace for Test 1263-2

FIGURE F-38. Vehicle Prior to Test 1263-3

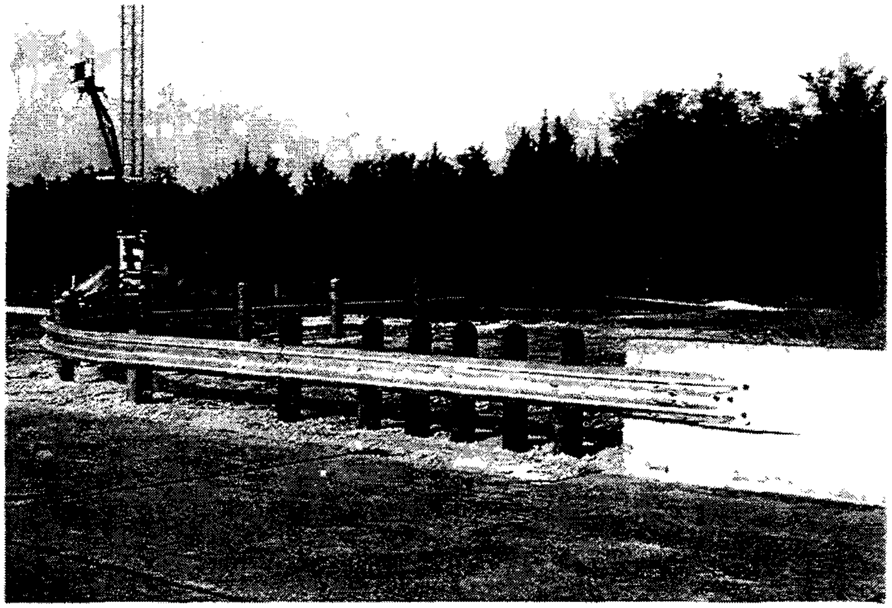
FIGURE F-39. Anthropometric Dummy Prior to Test 1263-3 which was evaluated in test 3 is shown in Figures F-40 through F-43. Test inertia mass of the vehicle was 1,800 lb (817 kg) and its gross static mass was 1,968 lb (893 kg). The height to the lower edge of the vehicle bumper was 11.5 in. (29.2 cm) and the height to the upper edge was 19.0 in. (40.3 cm). Additional dimensions and information on the test vehicle are given in Figure F-44.

The vehicle was directed into the guardrail as shown in Figure F-45using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the guardrail travelling at a speed of 60.2 mi/h (96.9 km/h) and the angle of impact was 20.7 degrees. As the vehicle deflected the rail, posts 8, 9, 10, and 11 all fractured at the ground line as designed. The vehicle was smoothly decelerated and contained. The sequential photographs of this test are shown in Figures F-46 and F-47.

As can be seen in Figures F-48 through F-51, the guardrail received moderate damage. Posts 8, 9, 10, and 11 all fractured at the ground line, and post 7 was pushed over in the soil. Posts 8 and 10 remained attached to the rail, while posts 9 and 11 were detached. The top corrugation of the rail had a 2.5 in. (5.4 cm) tear approximately 2 ft (0.6 m) upstream from post 8. However, the rail did not rupture and the test vehicle was contained. Maximum dynamic rail deflection was 14.1 ft (4.3 m) at post 9 and the maximum permanent residual deformation was 12.5 ft (3.81 m) also at post 9. Measurement of the movement of the rail element at posts 7 through 11 were taken and reported for specific times as noted in Table F-4.

Damage to the vehicle is shown in Figures F-52 and F-53. Maximum crush at bumper height was 21.0 in. (53.3 cm) at the left front corner and 20.0 in. (50.8 cm) at the right front corner. The wheel on the driver's side was pushed rearward 3.0 in. (7.6 cm), causing minor deformation of the floorpan. There were two dents in the roof above the rear passenger compartment which measured 11 in x 9 in x 1/4 in deep (27.9 cm x 22.9 cm x 0.6 cm deep) on the passengers side and 17 in x 11 in x 3/4 in deep (43.2 cm x 27.9 cm x 1.9 cm deep) on the driver's side. There was also damage to the front bumper, hood, grill, radiator, fan, the left and right front struts, the left and right front quarter panels, and the left and right doors.

Data from the accelerometer located at the center-of-gravity were digitized for evaluation, and occupant risk factors computed from this data are summarized below. In the longitudinal direction, occupant impact velocity was 34.3 ft/sec (10.5 m/sec) at 0.112 sec, the highest 0.010-second average ridedown acceleration was -8.9 g between 0.280 and 0.290 sec, and the



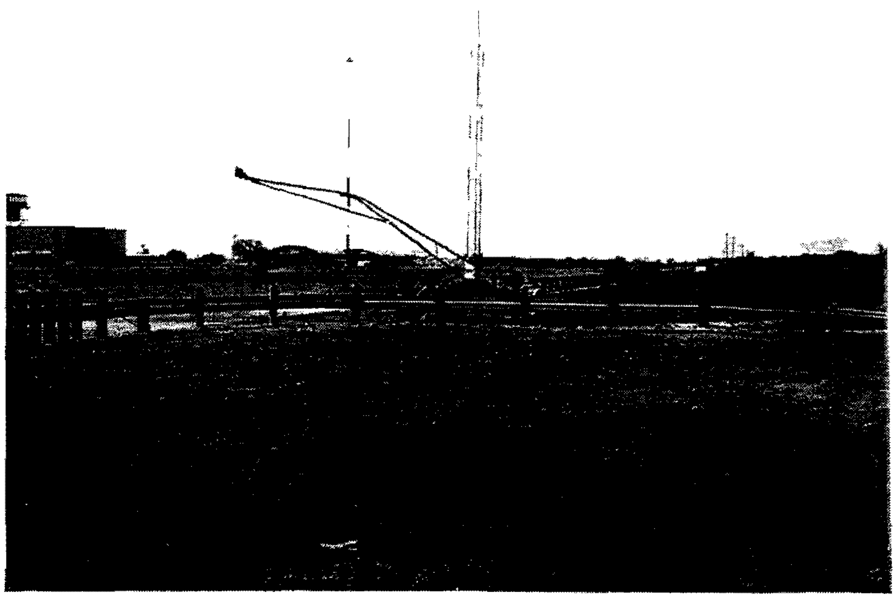
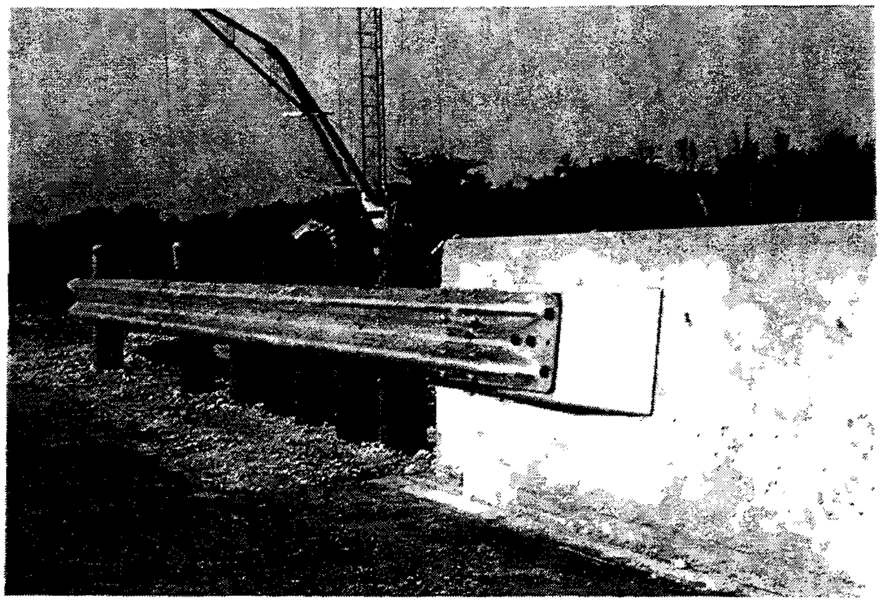


FIGURE F-40. Short Radius Guardrail Treatment before Test 1263-3



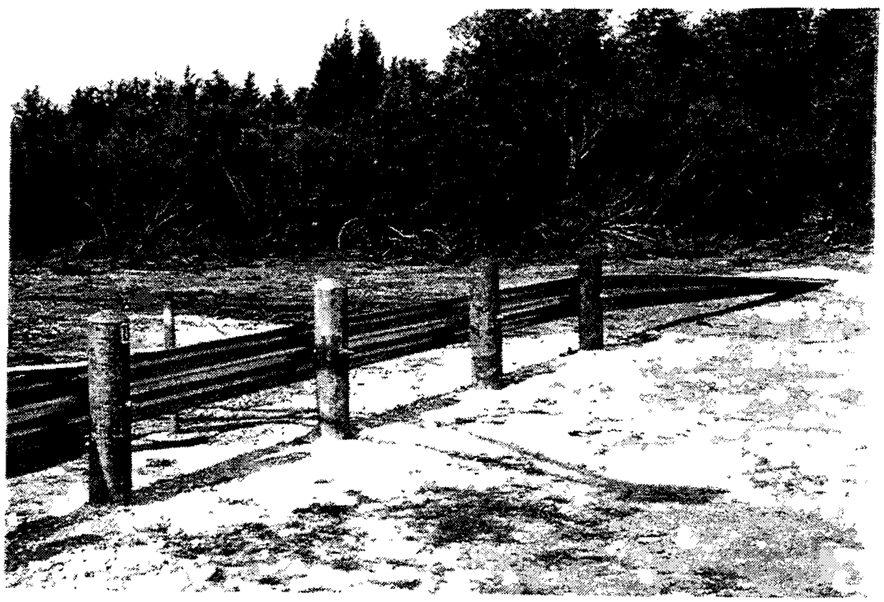


FIGURE F-41. End Treatments Used on Short Radius Guardrail for Test 1263-3

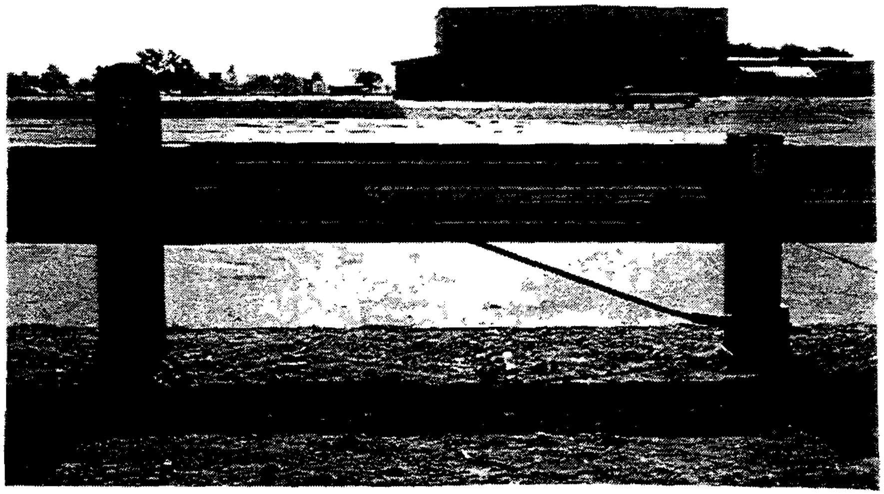


FIGURE F-42. Posts 6, 7, and 8 Prior to Test 1263-3

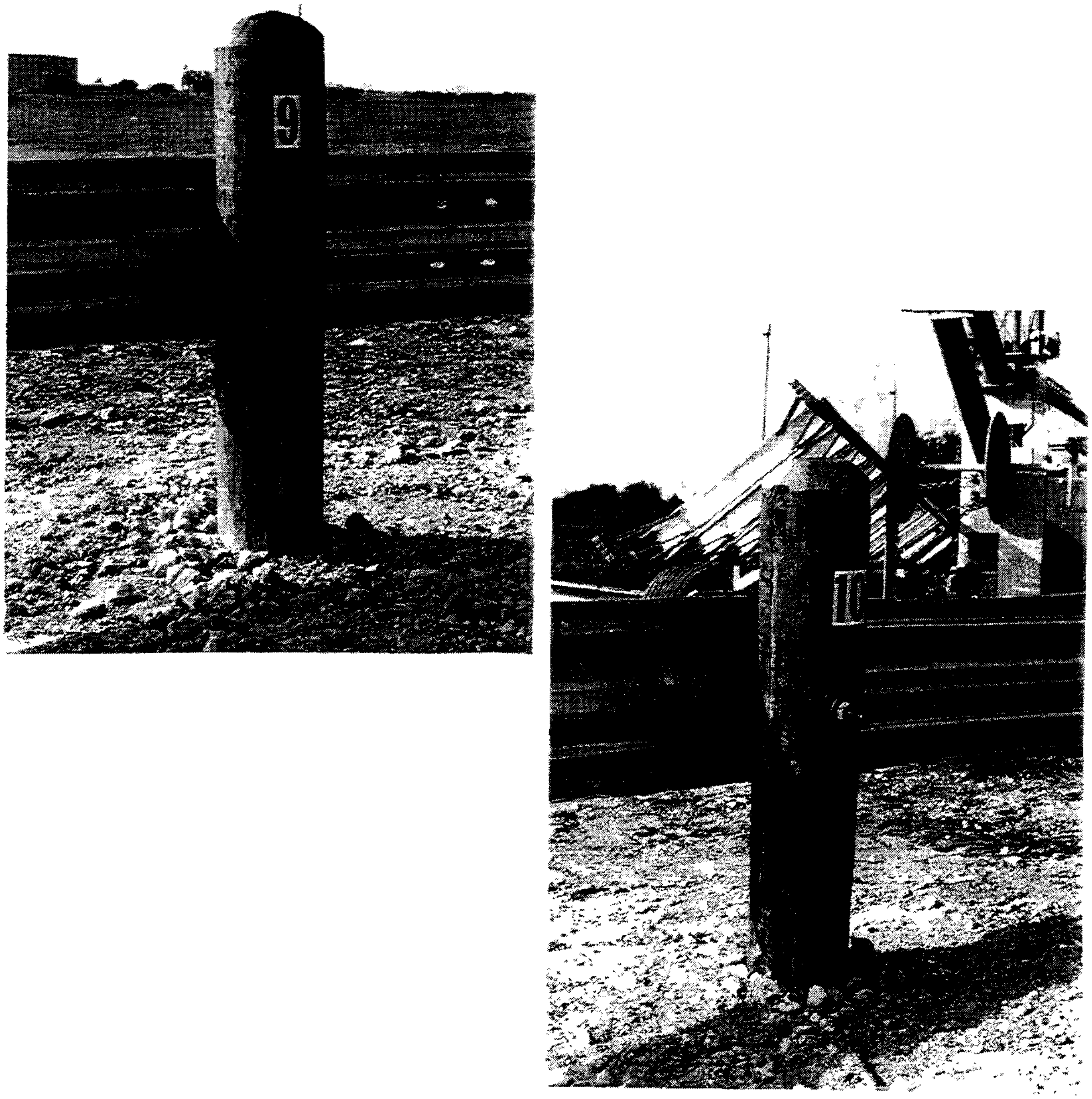


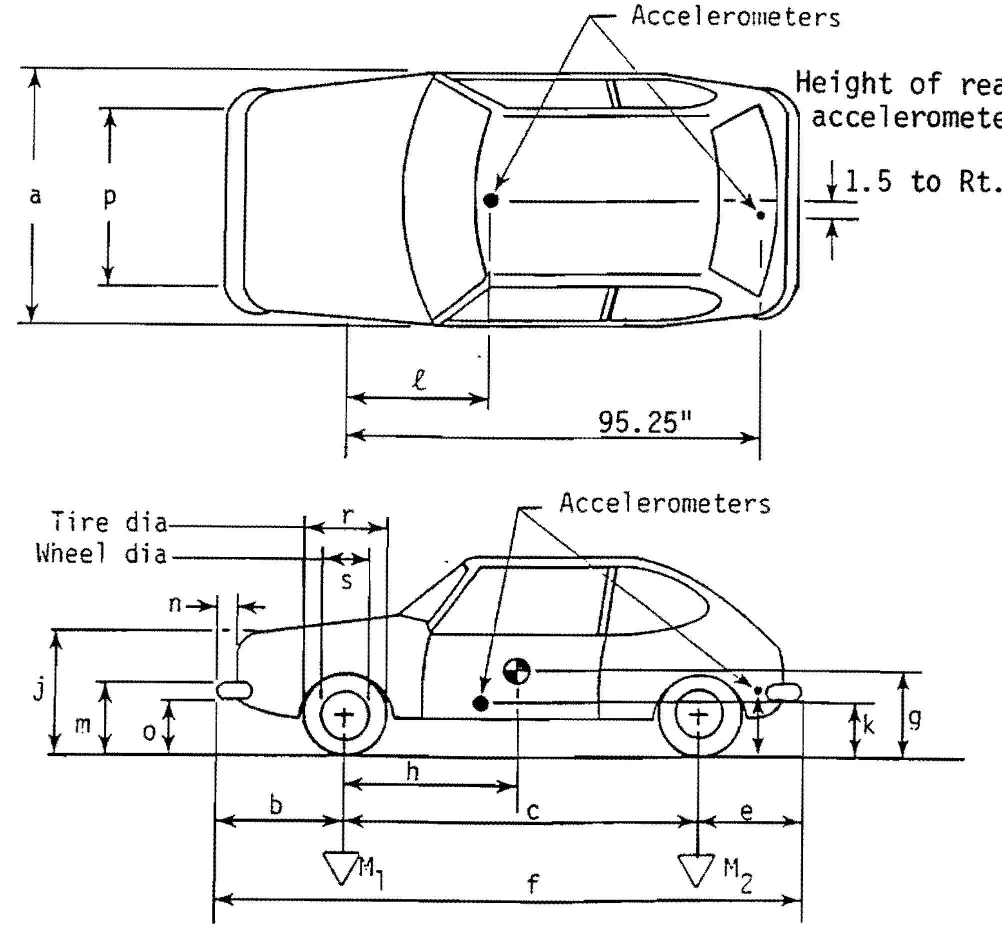
FIGURE F-43. Posts 9 and 10 Prior to Test 1263-3

Date: 8-17-92 Test No.: 1263-3 VIN: VX1BA1215H1L353059

Make: Yugo Model: GV Year: 1987 Odometer: 51072

Tire Size: 145 R13 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___ fair X badly worn ___



Vehicle Geometry - inches

a	60.5"	b	27.5"
c	84.25"	d*	55.5"
e	25"	f	136.75"
g		h	30.6"
i	----	j	30.25"
k	15"	ℓ	32"
m	19"	n	2.5"
o	11.5"	p	52.25"
r	22"	s	14.5"

Engine Type: V-4 Gas

Engine CID: 28A.064

Transmission Type:

XXXXXXXXXXXXX Manual

FWD XXXXXRWDXXXXXX4WDX

Body Type: 3 Door

Steering Column Collapse Mechanism:

- ___ Behind wheel units
- ___ Convoluted tube
- ___ Cylindrical mesh units
- ___ Embedded ball
- ___ NOT collapsible
- ___ Other energy absorption
- ___ Unknown

Brakes:

Front: disc X drum ___

Rear: disc ___ drum X

4-wheel weight for c.g. det. ℓf 552 rf 594 ℓr 323 rr 331

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	1167	1146	1226
M_2	639	654	742
M_T	1806	1800	1968

Note any damage to vehicle prior to test:

____

____

*d = overall height of vehicle

FIGURE F-44. Test Vehicle Properties (1263-3)

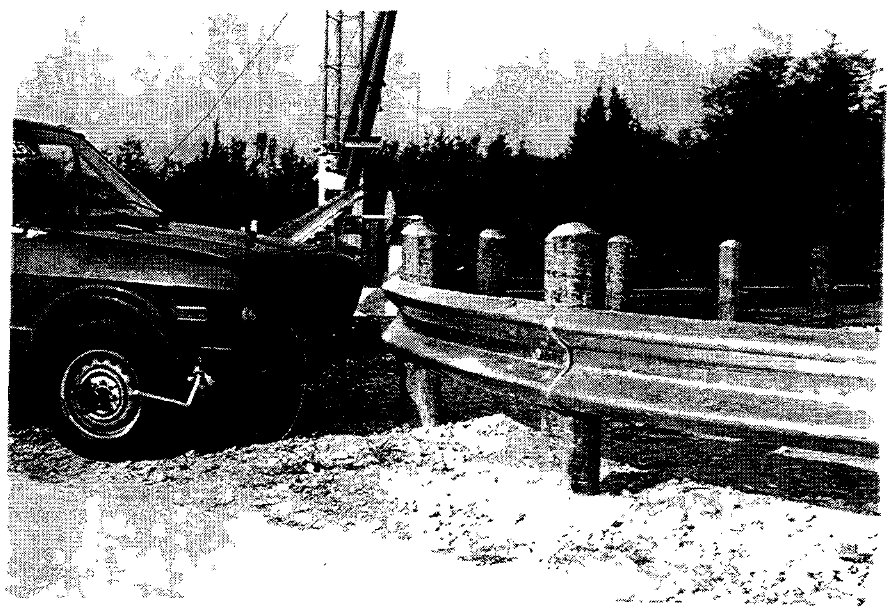
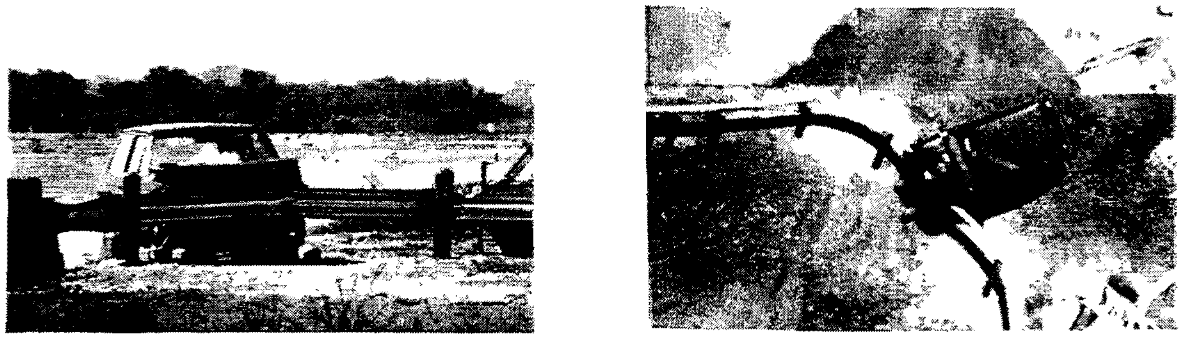
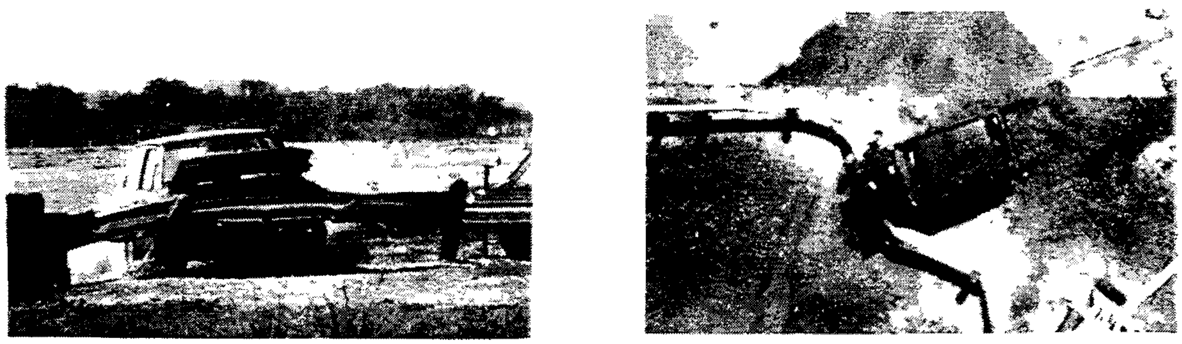


FIGURE F-45. Vehicle/Guardrail Geometrics for Test 1263-3

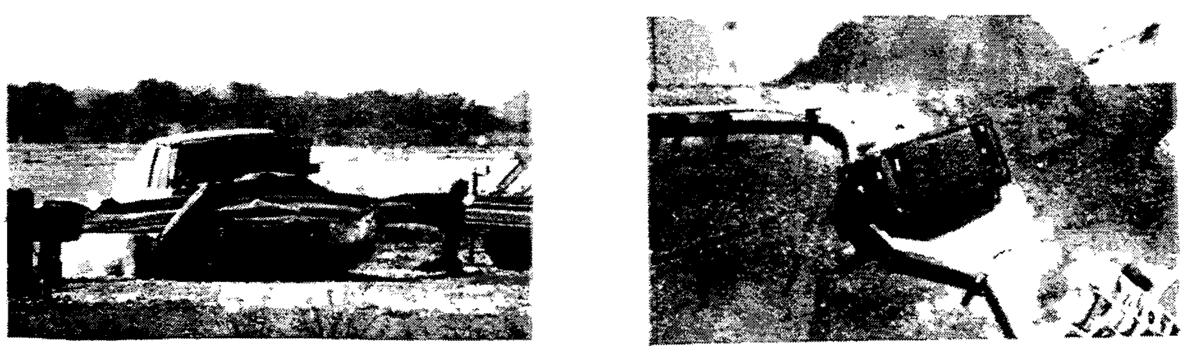
0.000 s



0.048 s

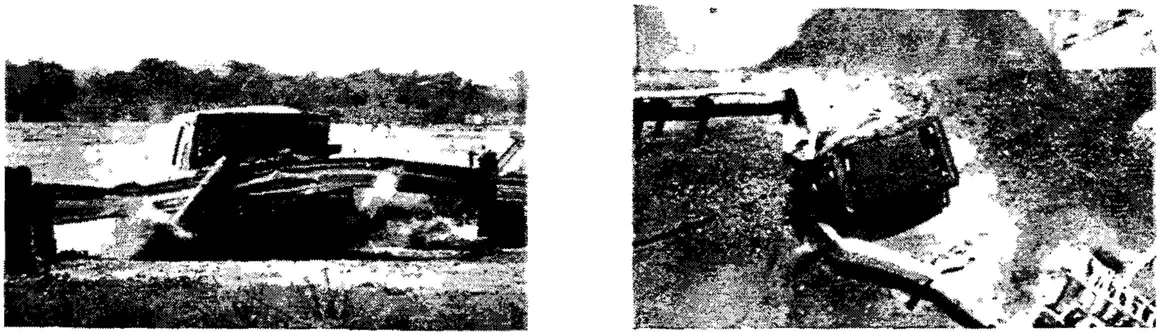


0.099 s



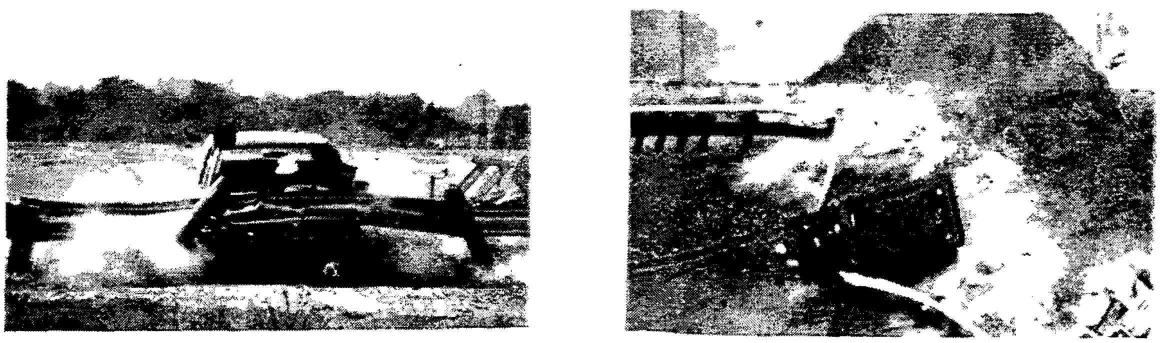
0.150 s

FIGURE F-46. Sequential Photographs for Test 1263-3 (Frontal and Overhead Views)



0.200 s

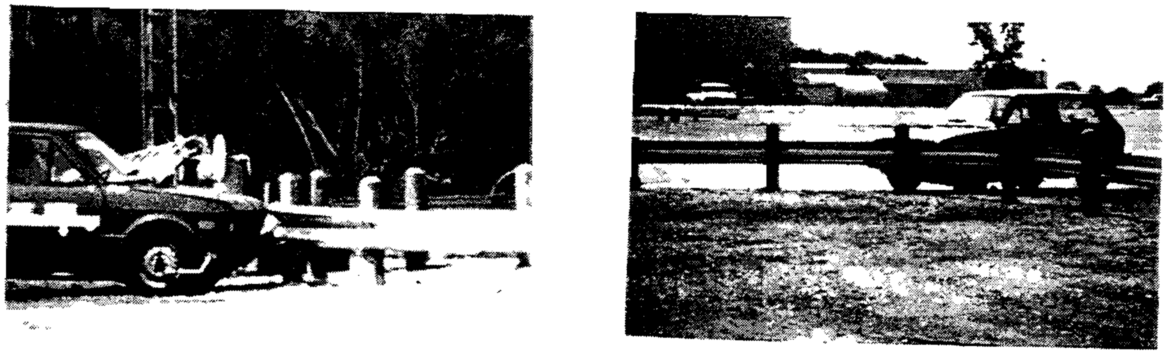
0.249 s



0.320 s

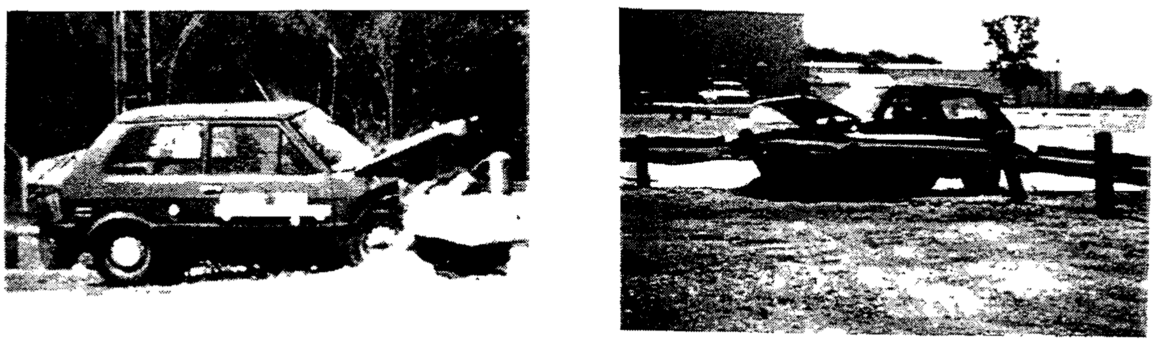
0.599 s

FIGURE F-46. Sequential Photographs for Test 1263-3 (Frontal and Overhead Views) (continued)



0.000 s

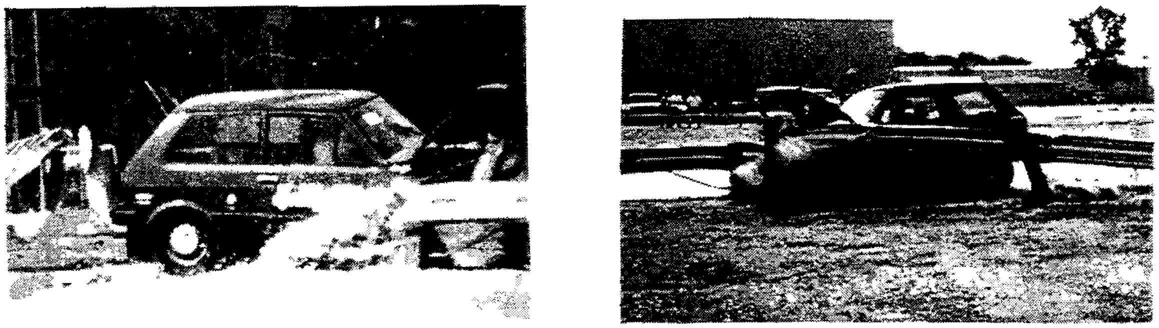
0.048 s



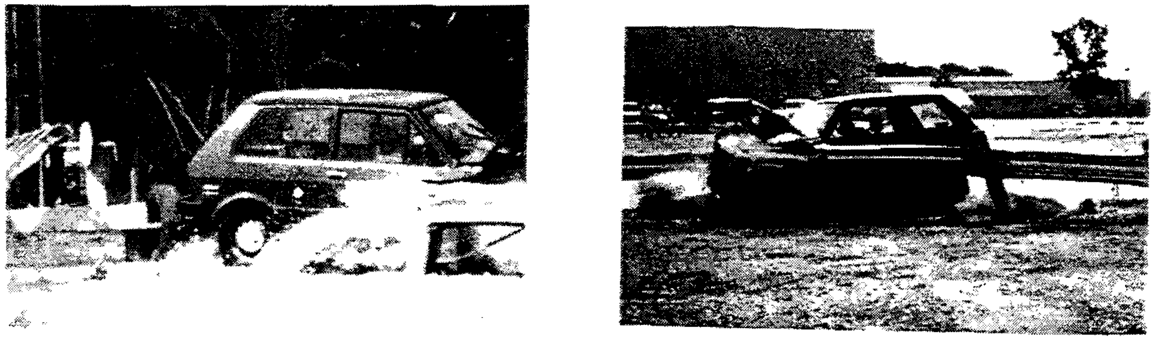
0.099 s

0.150 s

FIGURE F-47. Sequential Photographs for Test 1263-3 (Side Views)



0.200 s



0.249 s

0.320 s

0.599 s

FIGURE F-47. Sequential Photographs for Test 1263-3 (Side Views) (continued)

FIGURE F-48. Test Site after Test 1263-3

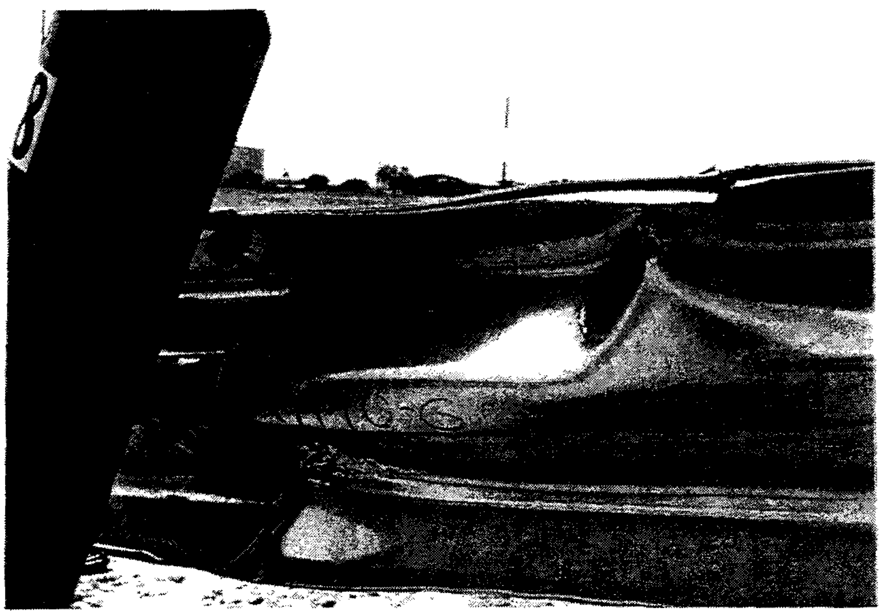
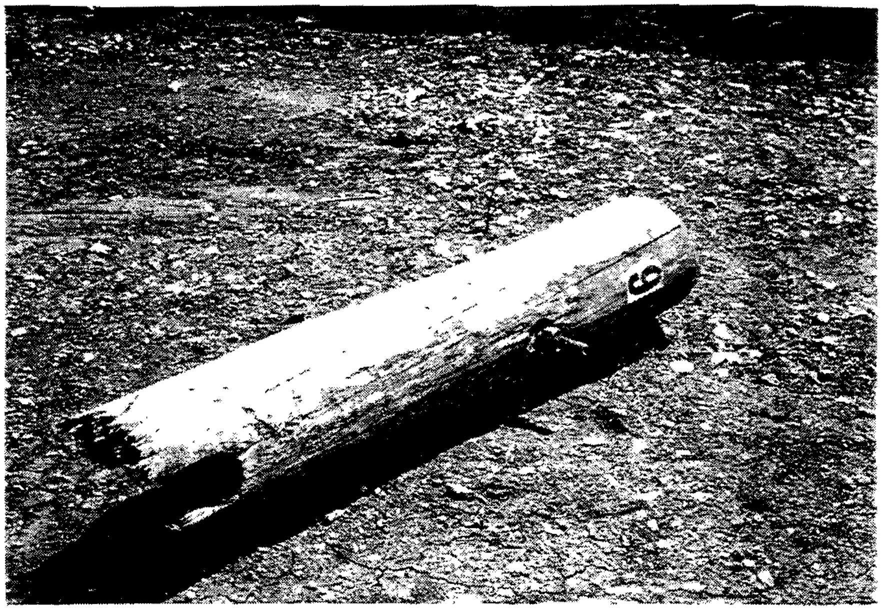


FIGURE F-49. Damage at Post 8, Test 1263-3

FIGURE F-50. Damage at Post 7, Test 1263-3



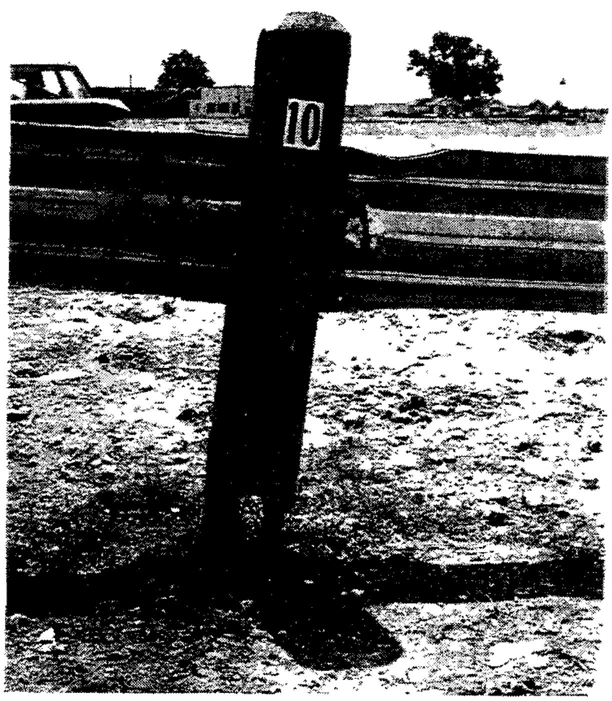


FIGURE F-51. Damage at Posts 9 and 10, Test 1263-3

TABLE F-4. Rail Movement During Test 1263-3

Time (sec)	Post 7	Post 8	Post 9	Post 10	Post 11
0.025	fwd 0.240	fwd 0.042	0.593	0.107	0
0.049	fwd 0.434	0.301	2.190	0.132	fwd 0.105
0.074	0.298	1.224	3.650	0.276	origin
0.099	origin	2.371	5.095	0.856	0.123
0.123	0.131	3.399	6.207	1.316	origin
0.148	0.174	4.585	7.170	2.145	origin
0.173	0.131	5.987	8.250	3.304	0.212
0.197	0.178	6.524	9.333	4.596	0.299
0.222	0.280	7.440	10.335	5.769	0.407
0.247	0.458	8.069	11.022	6.228	0.807
0.271	0.717	8.999	11.225	6.277	1.107
0.296	0.823	9.831	11.556	6.866	1.625
0.320	0.879	10.398	12.206	7.682	2.411
0.345	0.863	10.955	12.757	8.407	3.134
0.370	0.807	11.388	13.265	9.250	4.453
0.394	0.839	11.612	13.659	9.681	5.032
0.419	0.868	11.118	13.846	10.185	5.547
0.444	0.887	11.414	13.977	10.169	5.927
0.468	0.889	11.191	14.061	10.037	5.711
0.493	0.891	11.244	14.016	9.627	5.175

FIGURE F-52. Vehicle after Test 1263-3

FIGURE F-53. Anthropometric Dummy after Test 1263-3

maximum 0.050-second average acceleration was -13.2 g between 0.030 and 0.080 sec. In the lateral direction, occupant impact velocity was 7.9 ft/sec (2.4 m/sec) at 0.290 sec, the highest 0.010-second occupant ridedown acceleration was -3.5 g between 0.290 and 0.300 sec, and the maximum 0.050-second average acceleration was 3.4 g between 0.114 and 0.164 sec. Note that these values were all well within the maximum allowable values set forth in NCHRP Report 230. This and other pertinent information from the test are summarized in Figure F-54. Vehicular angular displacements are displayed in Figure F-55, and vehicular accelerations versus time traces, filtered at SAE J211 (Class 180), are presented in Figures F-56 through F-58.

In summary, this test was judged to be a success. As evident from the occupant risk criteria, the short radius guardrail contained and smoothly decelerated the test vehicle. The vehicle remained upright and stable throughout the impact event. There was not intrusion and only minimal deformation to the floor pan of the occupant compartment.

Test 1263-4 (4,500 lb/57.1 mph/24.7 deg)

This test was a transition test which evaluated the propensity of a vehicle to pocket or snag on the end of the bridge rail during impacts near the bridge end. The critical impact location for this test was determined to be 6 ft upstream from the end of the rigid bridge parapet. The critical impact point is defined as the location which maximizes the potential for vehicle contact on the end of the bridge rail. The test vehicle for this test was a 1982 Cadillac Sedan shown in Figure F-59. The completed test installation is shown in Figures F-60 through F-62. Test inertia mass of the vehicle was 4,500 lb (2041 kg), and its gross static mass was 4,500 lb (2,041 kg). The bumper height varied from 12.75 in. (32.4 cm) at its lower edge to 21 in. (53.3 cm) at its upper edge. Additional dimensional information for the test vehicle is located in Figure F-63. The vehicle was directed into the guardrail as shown in Figure F-64 using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the tubular W-beam transition 6 ft upstream from the end of the bridge rail at a speed of 57.1 mph (91.9 km/h) and at an angle of 24.7 degrees relative to the tangent section of rail along the primary roadway.

Although there was evidence of some wheel contact on the end of the safety shaped barrier, the transition smoothly contained and redirected the test vehicle. The vehicle lost contact with the barrier at 0.350 sec at a speed of 42.2 mph (67.9 km/h) and at an exit angle

Impact 0.099 sec 0.200 sec 0.320 sec

Test No. 1263-3
Date 08/17/92
Test Installation . . . Short-Radius Guardrail Treatment
Installation Length . . 100 ft (30 m)
Max. Dynamic Movement . 14.1 ft (4.3 m)
Max. Perm. Movement . . 12.5 ft (3.8 m)
Test Vehicle . . . . . . 1987 Yugo GV
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
  Gross Static . . . . . 1,970 lb (894 kg)
Vehicle Damage Classification
  TAD 12FD6
  CDC 12FCEW4
Maximum Vehicle Crush. . 21.0 in (53.3 cm)

Impact Speed. . . . . 60.2 mi/h (96.9 km/h)
Impact Angle. . . . . 20.7 deg
Speed at Parallel . . N/A
Exit Speed . . . . . N/A
Exit Trajectory . . . N/A
Vehicle Accelerations at center-of-gravity
  (Max. 0.050-sec Average)
  Longitudinal. . . . -13.2 g
  Lateral . . . . . . 3.4 g
Occupant Impact Velocity at true c.g.
  Longitudinal. . . . 34.3 ft/s (10.5 m/s)
  Lateral . . . . . . 7.9 ft/s (2.4 m/s)
Occupant Ridedown Accelerations
  Longitudinal . . . -8.9 g
  Lateral . . . . . . -3.5 g

FIGURE F-54. Summary of Results for Test 1263-3

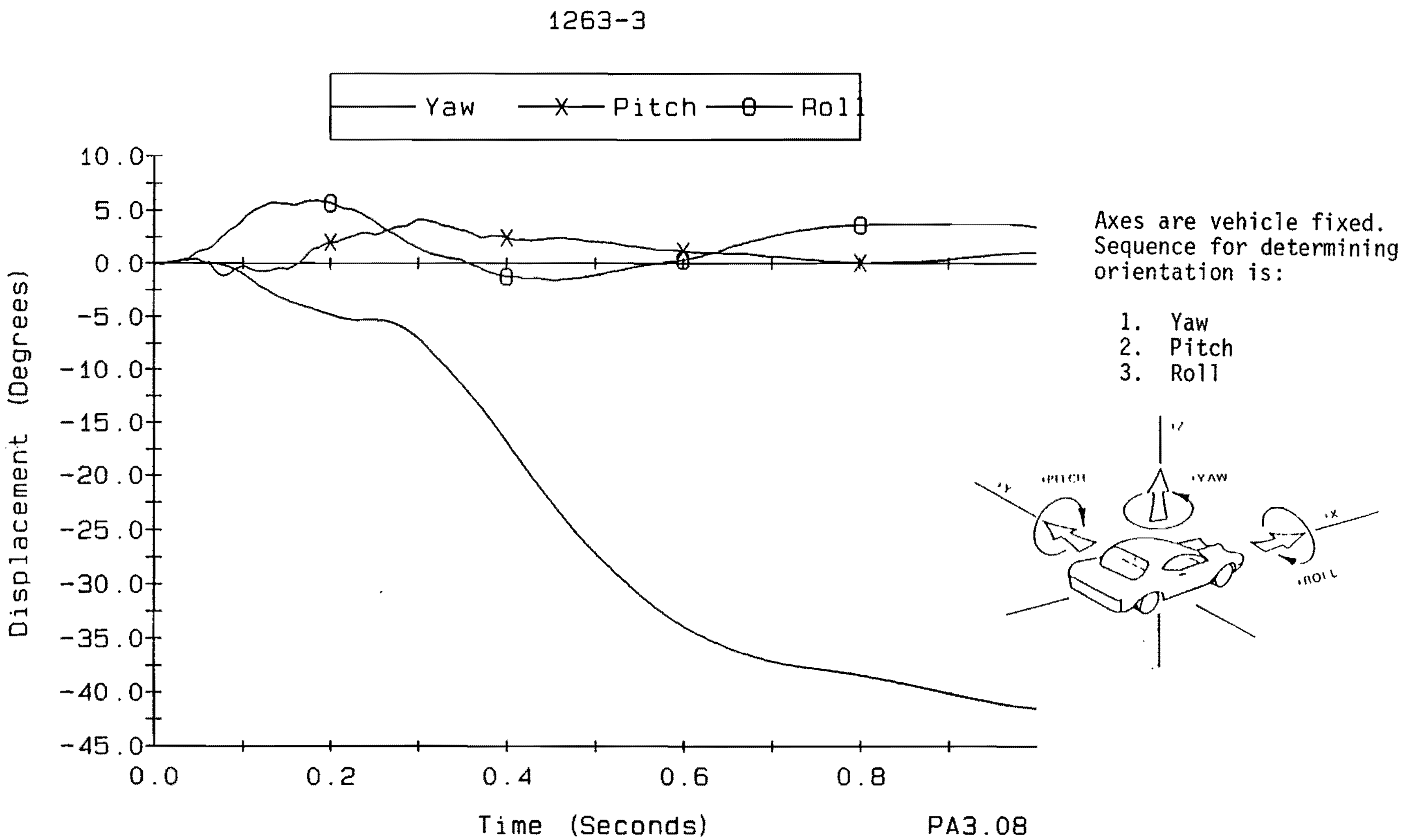


FIGURE F-55. Vehicle Angular Displacements for Test 1263-3

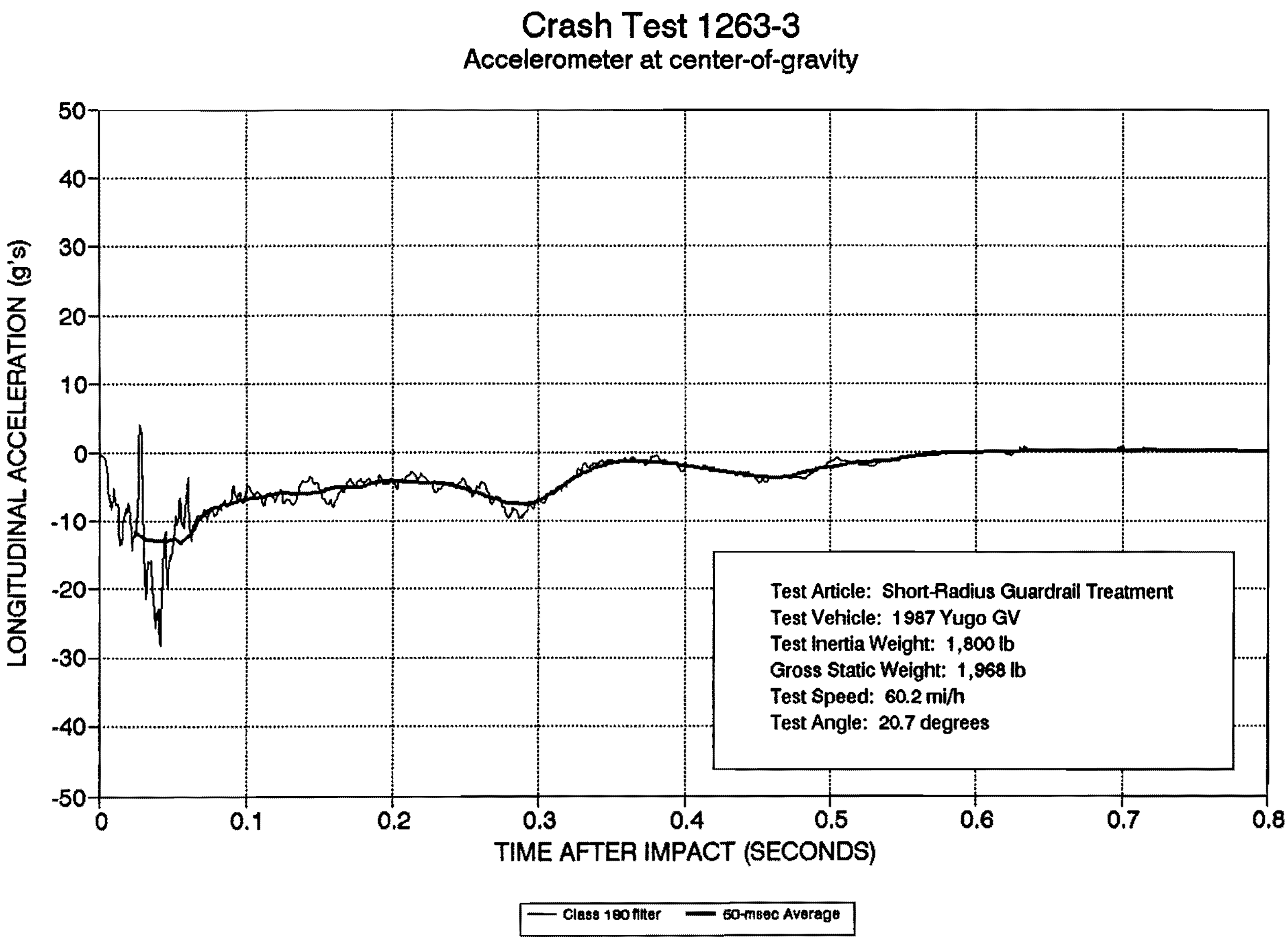


FIGURE F-56. Longitudinal Accelerometer Trace for Test 1263-3

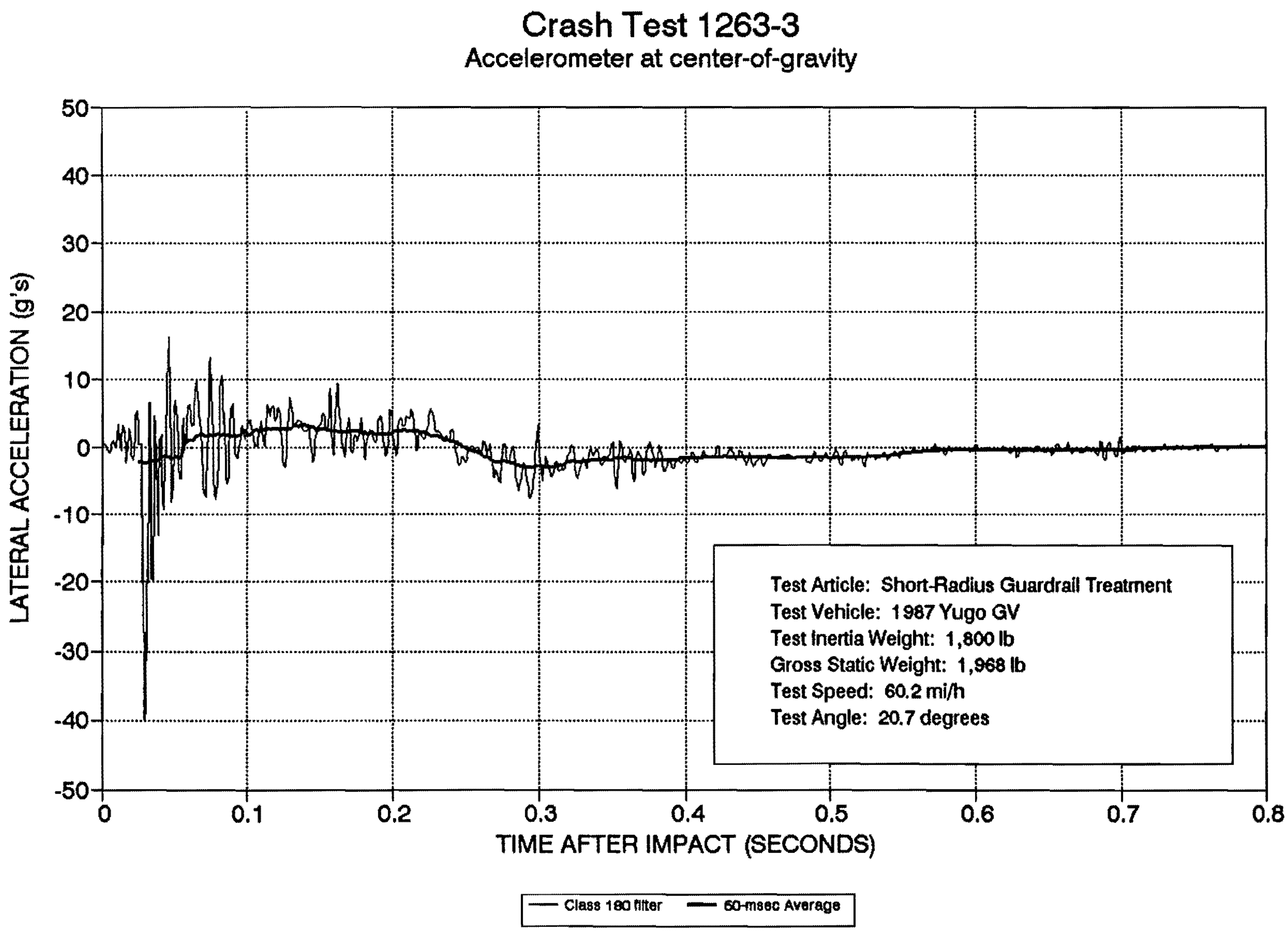


FIGURE F-57. Lateral Accelerometer Trace for Test 1263-3

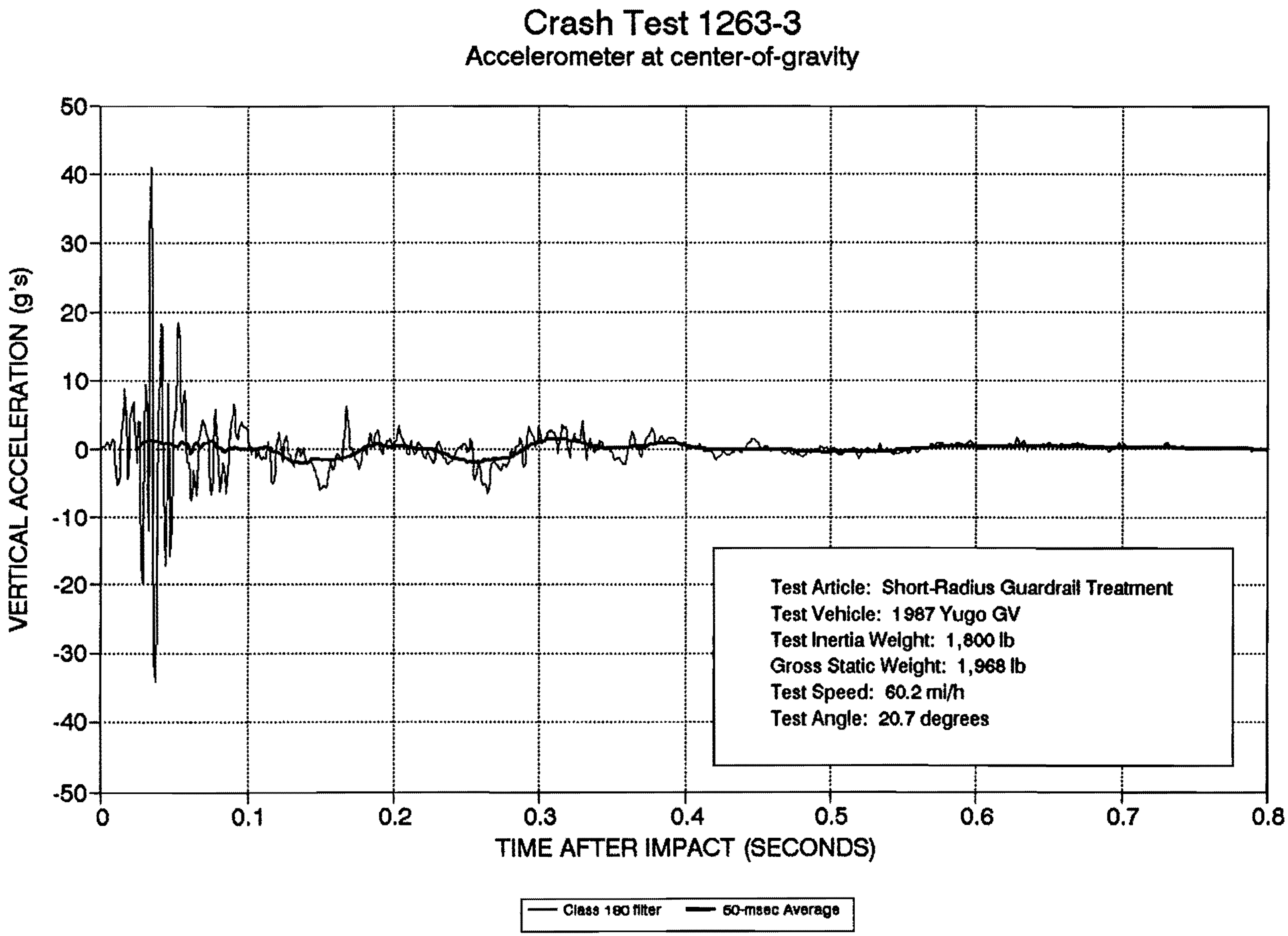


FIGURE F-58. Vertical Accelerometer Trace for Test 1263-3

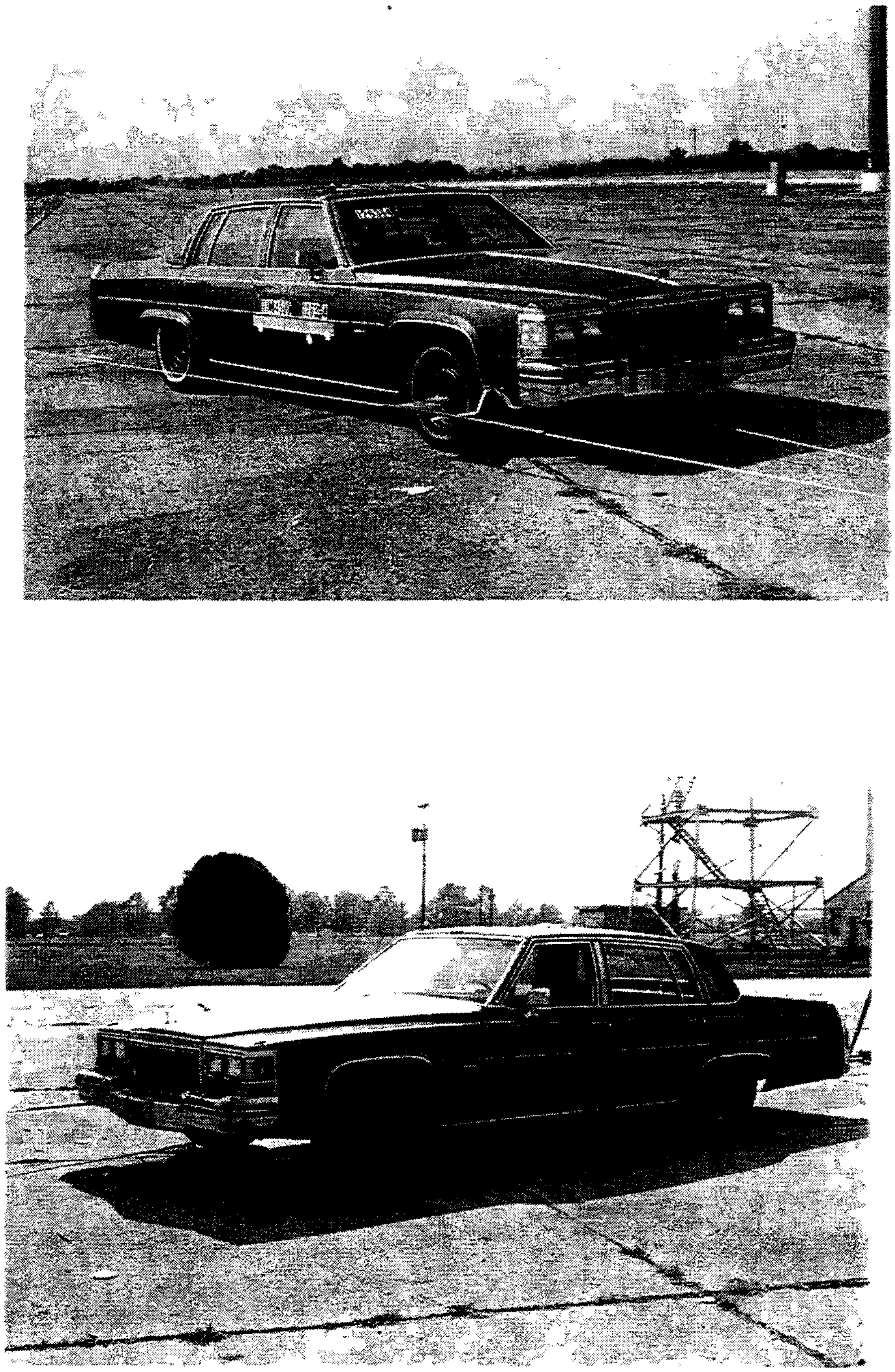


FIGURE F-59. Vehicle Prior to Test 1263-4

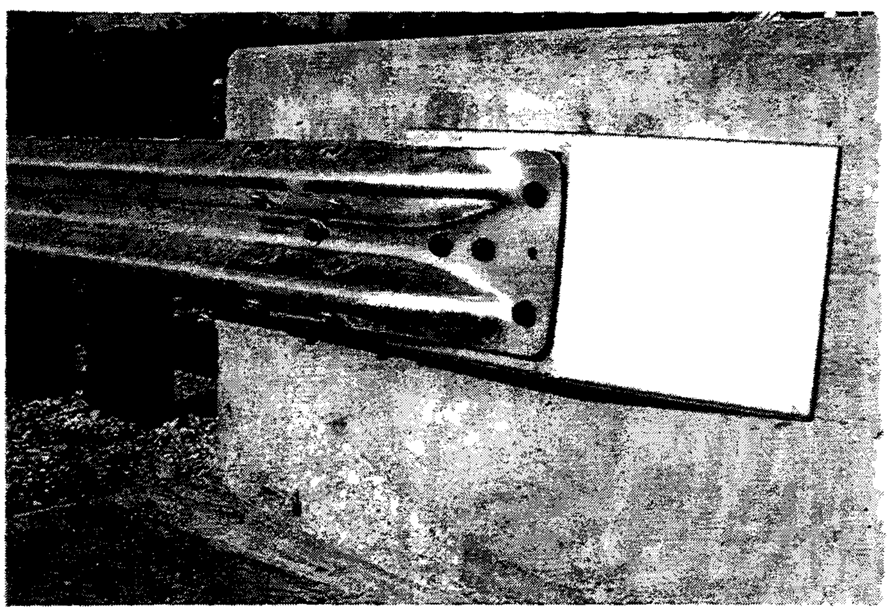
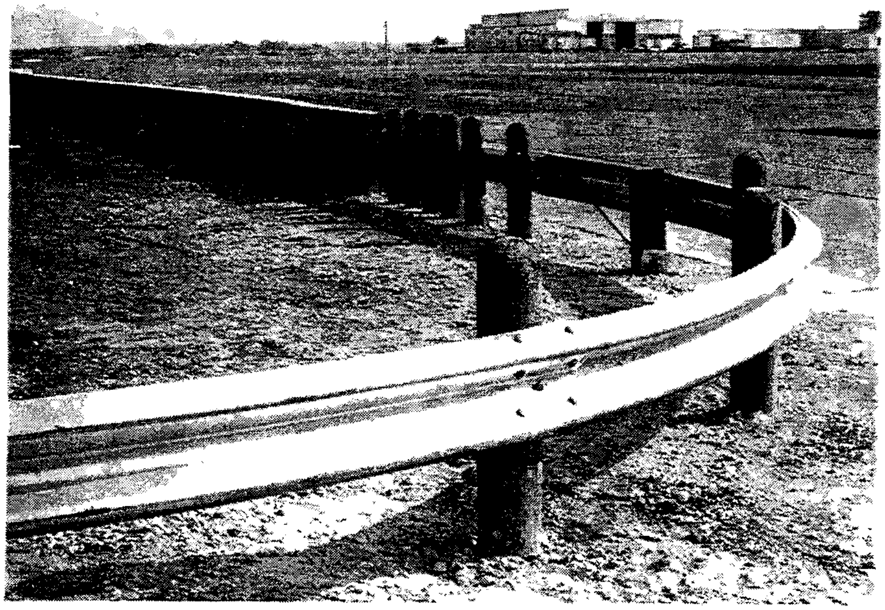
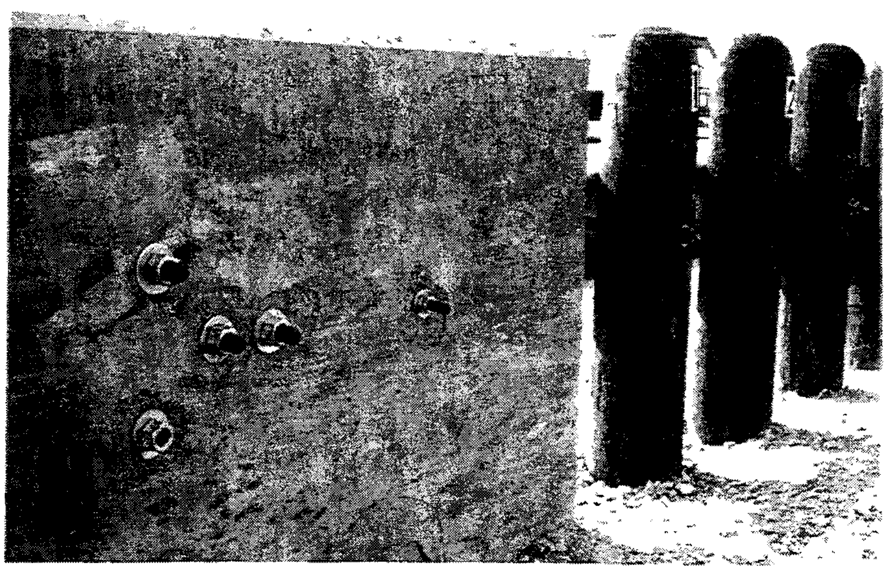


FIGURE F-60. Guardrail Connection with Concrete Safety Shape before Test 1263-4 (Front View)





. **FIGURE F-61.** **Guardrail Connection with Concrete Safety Shape before Test 1263-4 (Rear View)**

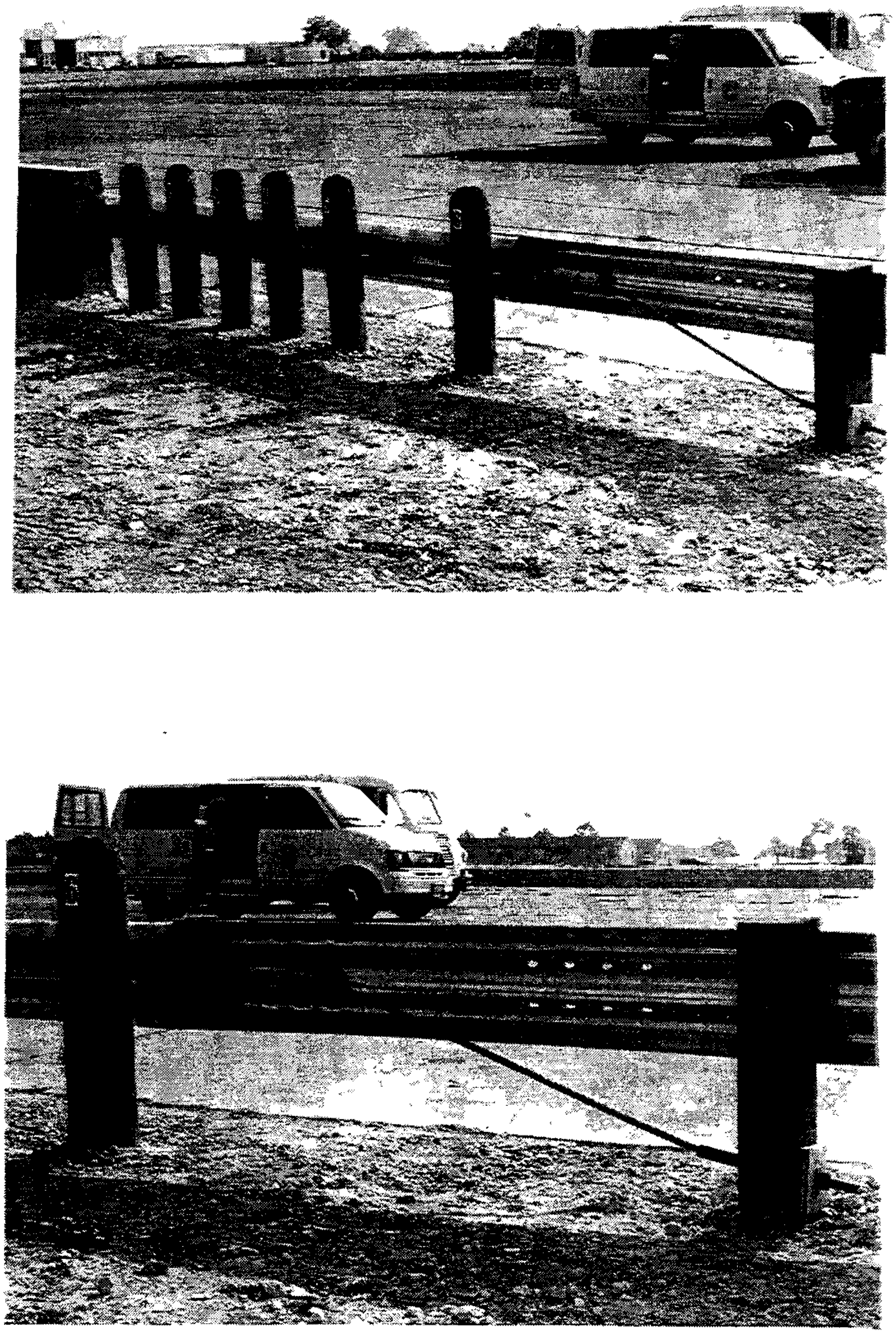


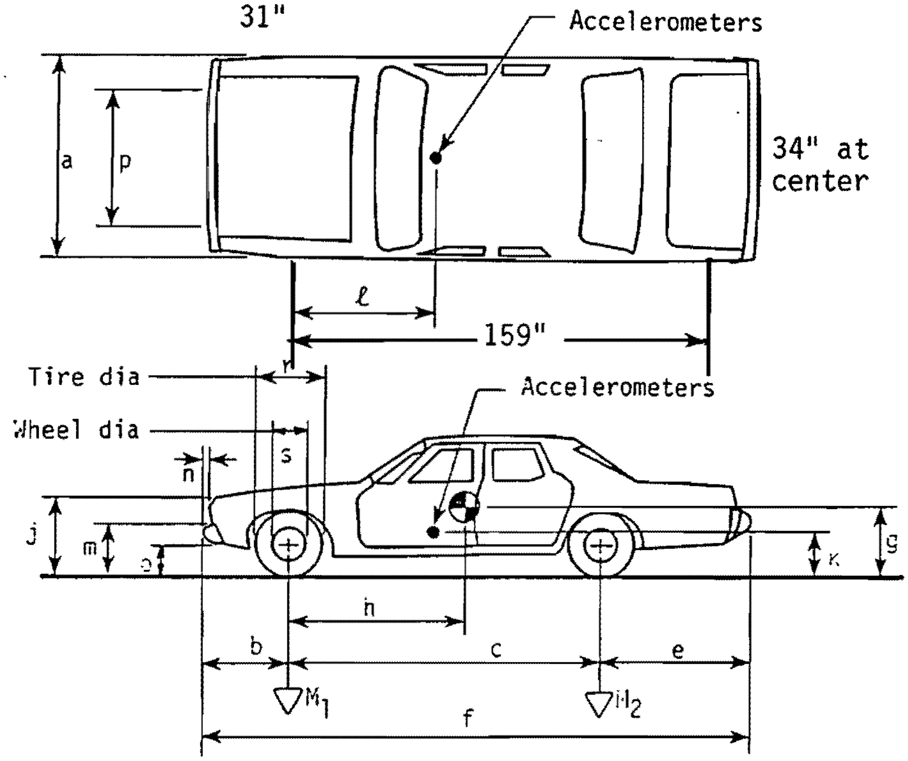
FIGURE F-62. Guardrail Transition Section before Test 1263-4

Date: 8-21-92 Test No.: 1263-4 VIN: 1G6AD69NXC9129330

Make: Cadillac Model: Sedan Year: 1982 Odometer: 101237

Tire Size: P215 75R15 Ply Rating: ______ Bias Ply: ___ Belted: ___ Radial: X

Height of rear accelerometer: 31"



Tire Condition: good ___
fair X
badly worn ___

Vehicle Geometry - inches

a	76.75"	b	43"
c	121.5"	d*	57.75"
e	57"	f	221.5"
g		h	55.2"
i	----	j	34.25"
k	19"	ℓ	51.5"
m	21"	n	4"
o	12.75"	p	61.75"
r	27.5"	s	16.25"

4-wheel weight for c.g. det. ℓf 1269 rf 1188 ℓr 1018 rr 1026

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2403	2457	
M_2	1799	2043	
M_T	4202	4500	

Note any damage to vehicle prior to test:

Windshield cracked (marked)

*d = overall height of vehicle

Engine Type: Diesel

Engine CID: 5.7 L

Transmission Type:

Automatic ~~or Manual~~
~~FWD or~~ RWD ~~or 4WD~~

Body Type: Sedan

Steering Column Collapse Mechanism:

___Behind wheel units
___Convoluted tube
___Cylindrical mesh units
___Embedded ball
___NOT collapsible
___Other energy absorption
___Unknown

Brakes:

Front: disc X drum ___

Rear: disc ___ drum X

FIGURE F-63. Test Vehicle Properties (1263-4)

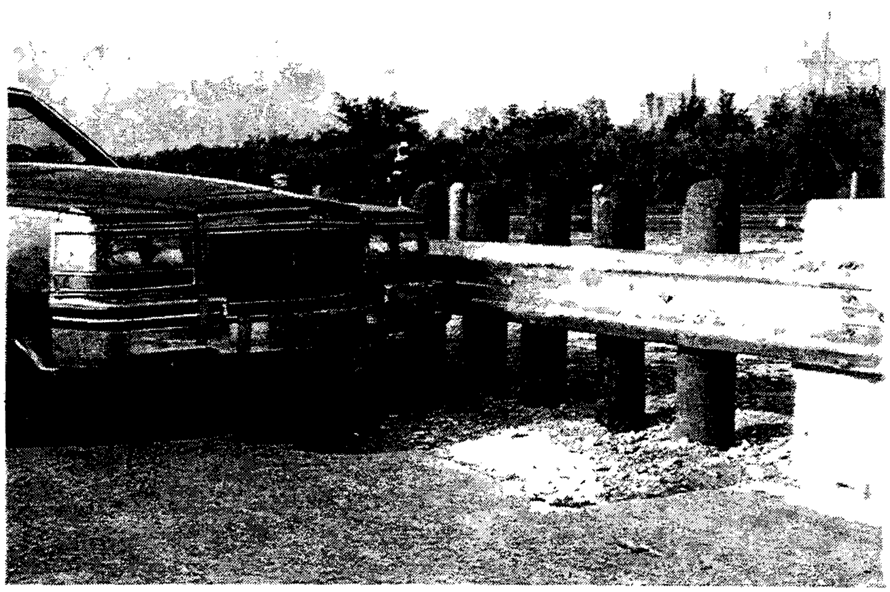


FIGURE F-64. Vehicle/Guardrail Geometrics for Test 1263-4 of 9 degrees. Subsequent to losing contact, damage to the left side of the vehicle steered it back into the barrier and a secondary impact occurred at approximately 1.550 sec. During this secondary impact, the vehicle sustained additional damage to the left front corner and roof. The vehicle stayed in contact with the concrete barrier and finally came to rest 161 ft from the point of impact.

Damage to the transition is shown in Figures F-65 through F-67. Post 2, the second post upstream from the bridge end, was gouged at the base approximately 5.5 inches above ground level. There was evidence of wheel contact at the base of the concrete bridge rail, and the tubular W-beam was deformed slightly from the point of impact to the concrete barrier. The terminal connection on the face of the concrete rail performed well and showed no signs of distress.

As shown in Figure F-68, damage to the vehicle was minor for a test of this severity. The damage was concentrated at the left front corner and left front wheel area. Maximum crush was measured to be 13 in. (33.0 cm) at bumper height, and the wheelbase on the left side was reduced by 15 in. (38.1 cm). The floor pan on the driver's side was deformed approximately 2 in. (5.1 cm), and there was some buckling of the roof panel over the "B" pillar area. The sheet metal door skin on the driver's door snagged on the end shoe and remained attached to the guardrail. There was also damage to the left front tire and rim, left front upper and lower A-arms, left front tie rod ends, frame, hood, grill, and windshield.

Data from the accelerometer located at the center of gravity were digitized for evaluation and occupant risk factors were computed as follows. In the longitudinal direction, occupant impact velocity was 27.6 ft/sec (8.4 m/sec) at 0.163 sec, the highest 0.010-second average ridedown acceleration was -4.8 g between 0.231 and 0.241 sec, and the maximum 0.050-second average acceleration was -9.1 g between 0.082 and 0.132 sec. In the lateral direction, occupant impact velocity 25.4 ft/sec (7.7 m/sec) at 0.121 sec, the highest 0.010-second occupant ridedown acceleration was -7.7 g between 0.222 and 0.232 sec, and the maximum 0.050-second average acceleration was -10.5 g between 0.068 and 0.118 sec. This data and other pertinent information from the test are summarized in Figure F-69, Sequential photographs of the impact are shown in Figures F-70 and F-71. Vehicular angular displacements are displayed in Figure F-72, and vehicular accelerations plotted versus time are presented in Figures F-73 through F-75.

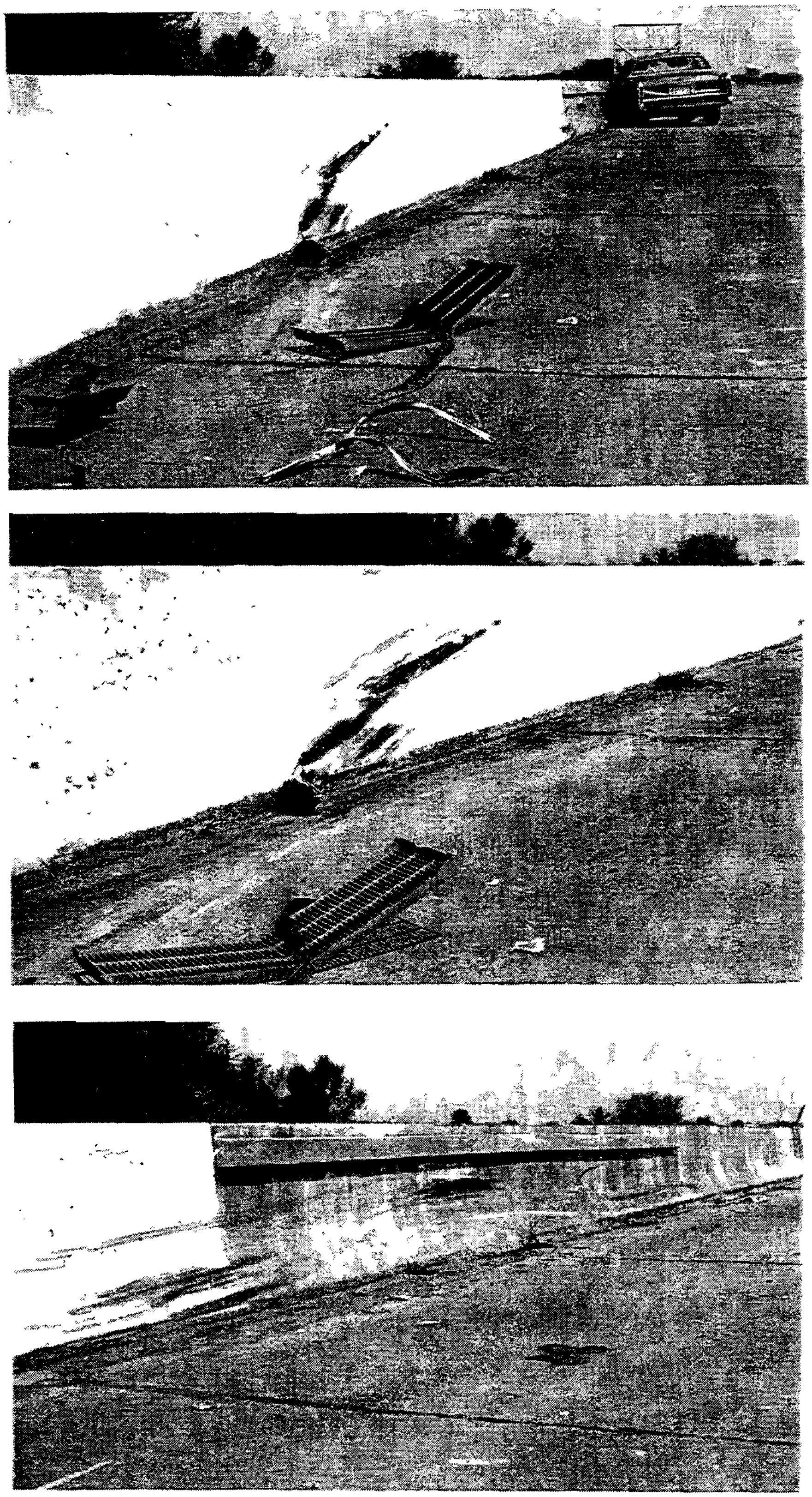


FIGURE F-65. Damage at Secondary Impact, Test 1263-4

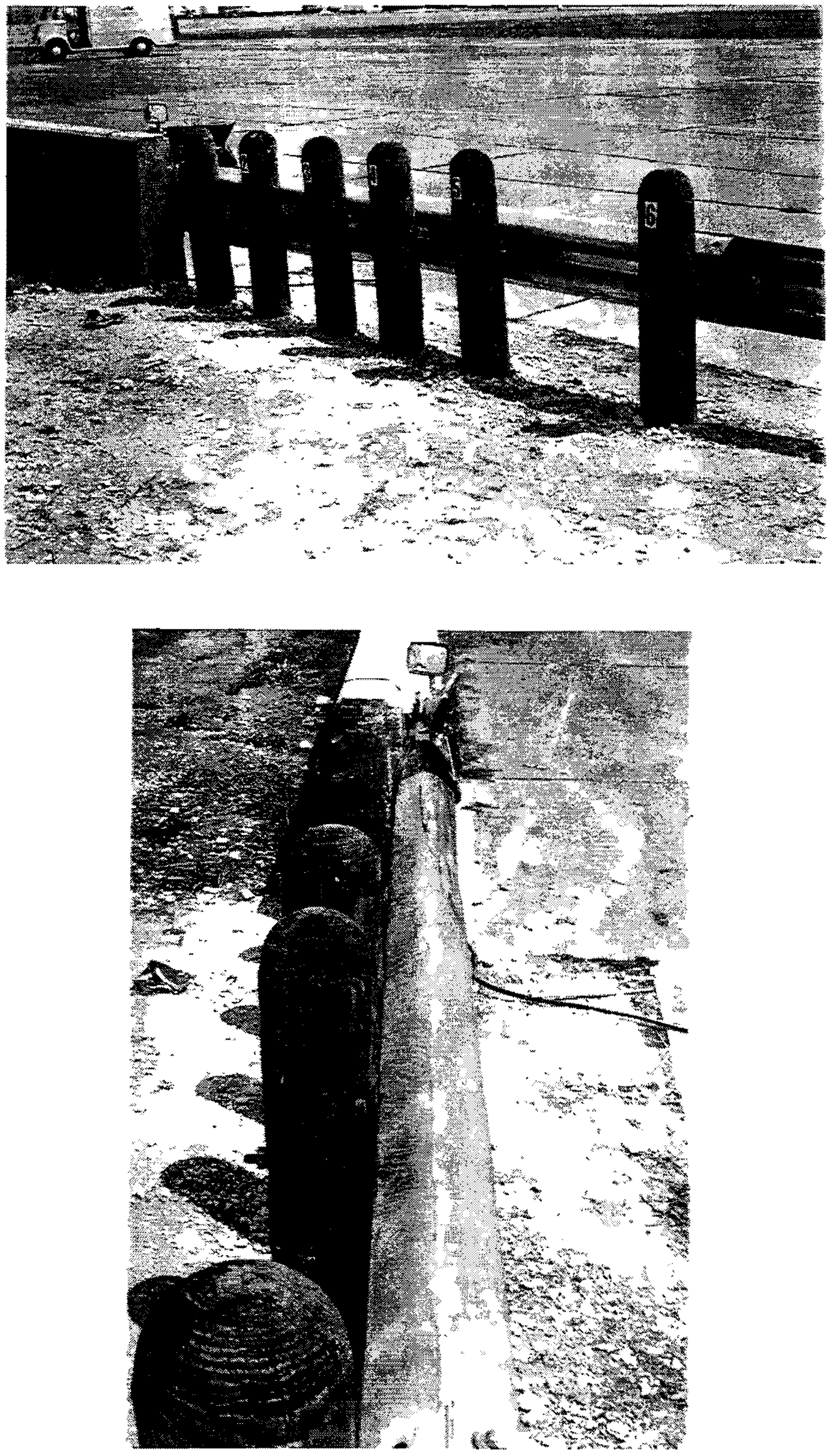


FIGURE F-66. Guardrail End Treatment after Test 1263-4

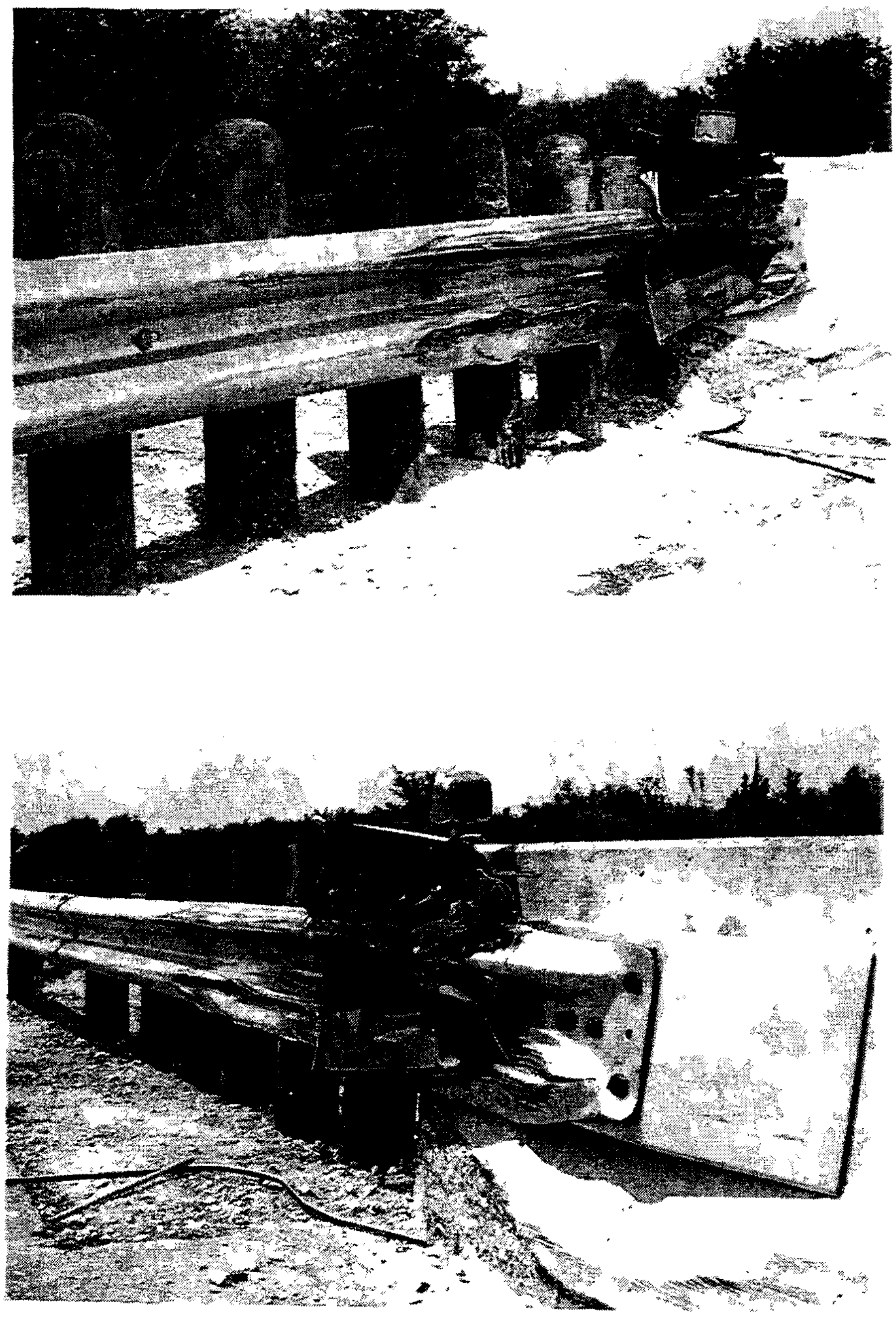
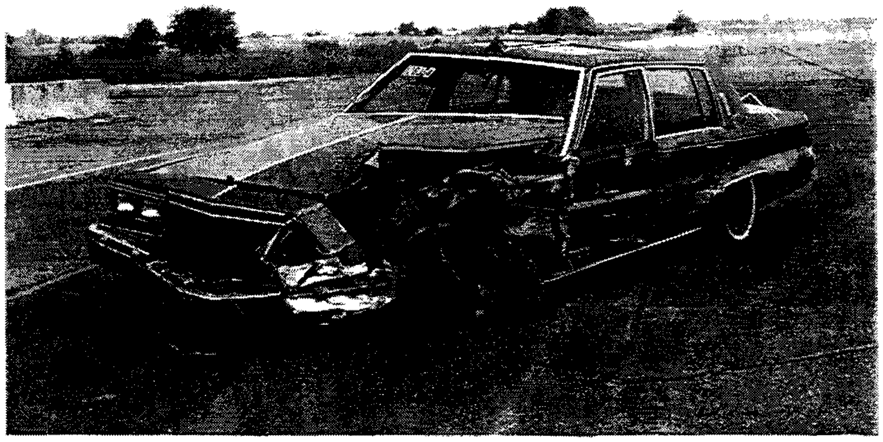


FIGURE F-67. Damage at Terminal Connection with Concrete Safety Shape, Test 1263-4



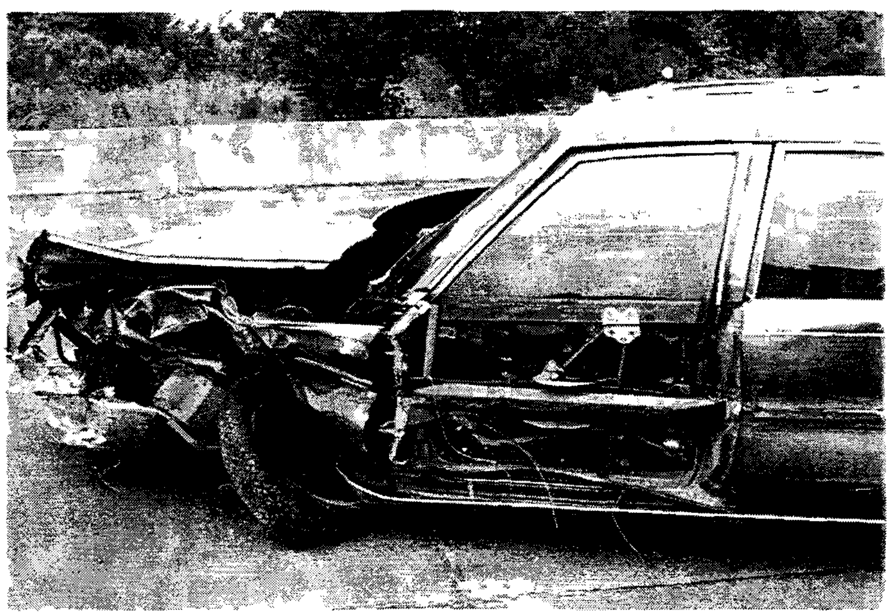
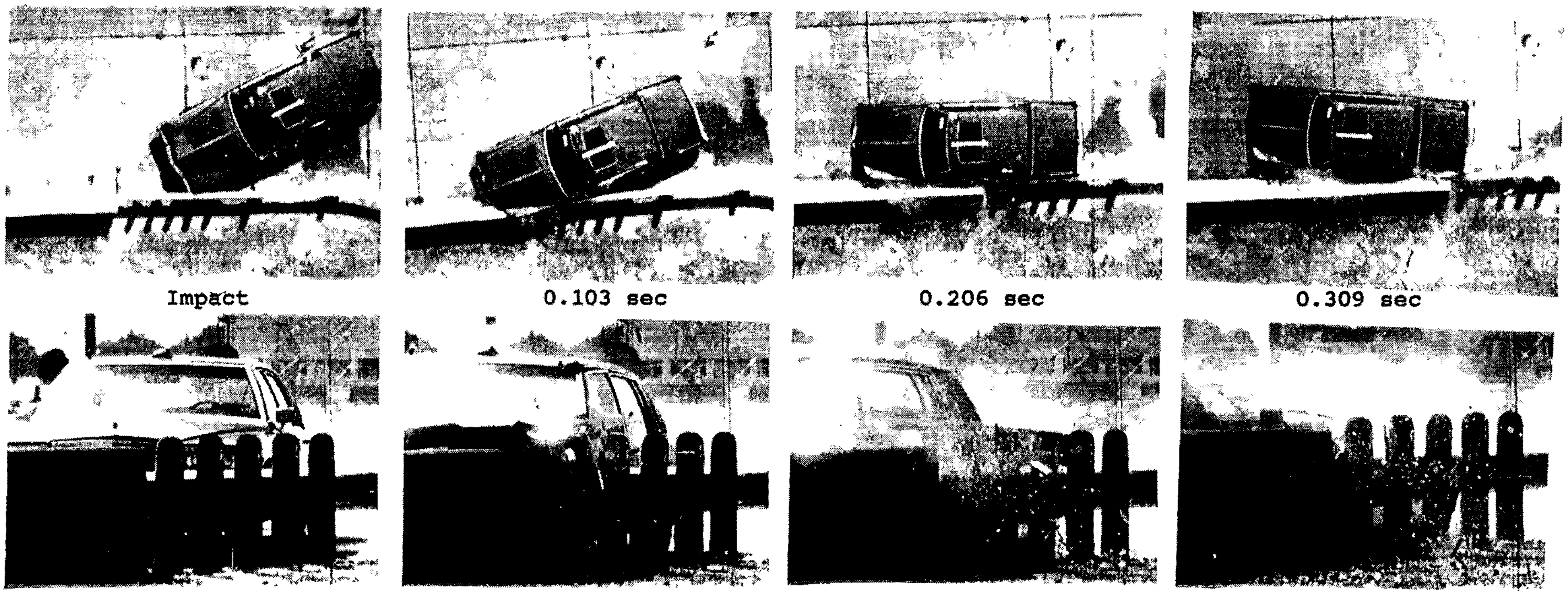


FIGURE F-68. Vehicle after Secondary Impact, Test 1263-4



Test No. 1263-4
Date 08/27/92
Test Installation . . . Short-Radius Guardrail Treatment
Installation Length . . 100 ft (30 m)
Max. Dynamic Movement . Not Obtained
Max. Perm. Movement . . 2.0 in (5.1 cm)
Test Vehicle . . . . . . 1982 Cadillac Sedan
Vehicle Weight
  Test Inertia . . . . . 4,500 lb (2,041 kg)
  Gross Static . . . . . 4,500 lb (2,014 kg)
Vehicle Damage Classification
  TAD 11FL7 11LD1
  CDC 11FLEK5 11LDES1
Maximum Vehicle Crush. . 13.0 in (33.0 cm)

Impact Speed. . . . . 57.1 mi/h (91.9 km/h)
Impact Angle. . . . . 24.7 deg
Speed at Parallel . . 44.9 mi/h (72.2 km/h)
Exit Speed . . . . . 42.2 mi/h (67.9 km/h)
Exit Trajectory . . . 9.0 deg
Vehicle Accelerations at center-of-gravity
  (Max. 0.050-sec Average)
  Longitudinal. . . . -9.1 g
  Lateral . . . . 10.5 g
  Occupant Impact Velocity at true c.g.
  Longitudinal. . . . 27.6 ft/s (8.4 m/s)
  Lateral . . . . 25.4 ft/s (7.7 m/s)
  Occupant Ridedown Accelerations
  Longitudinal . . . -4.8 g
  Lateral . . . . -7.7 g

FIGURE F-69. Summary of Results for Test 1263-4

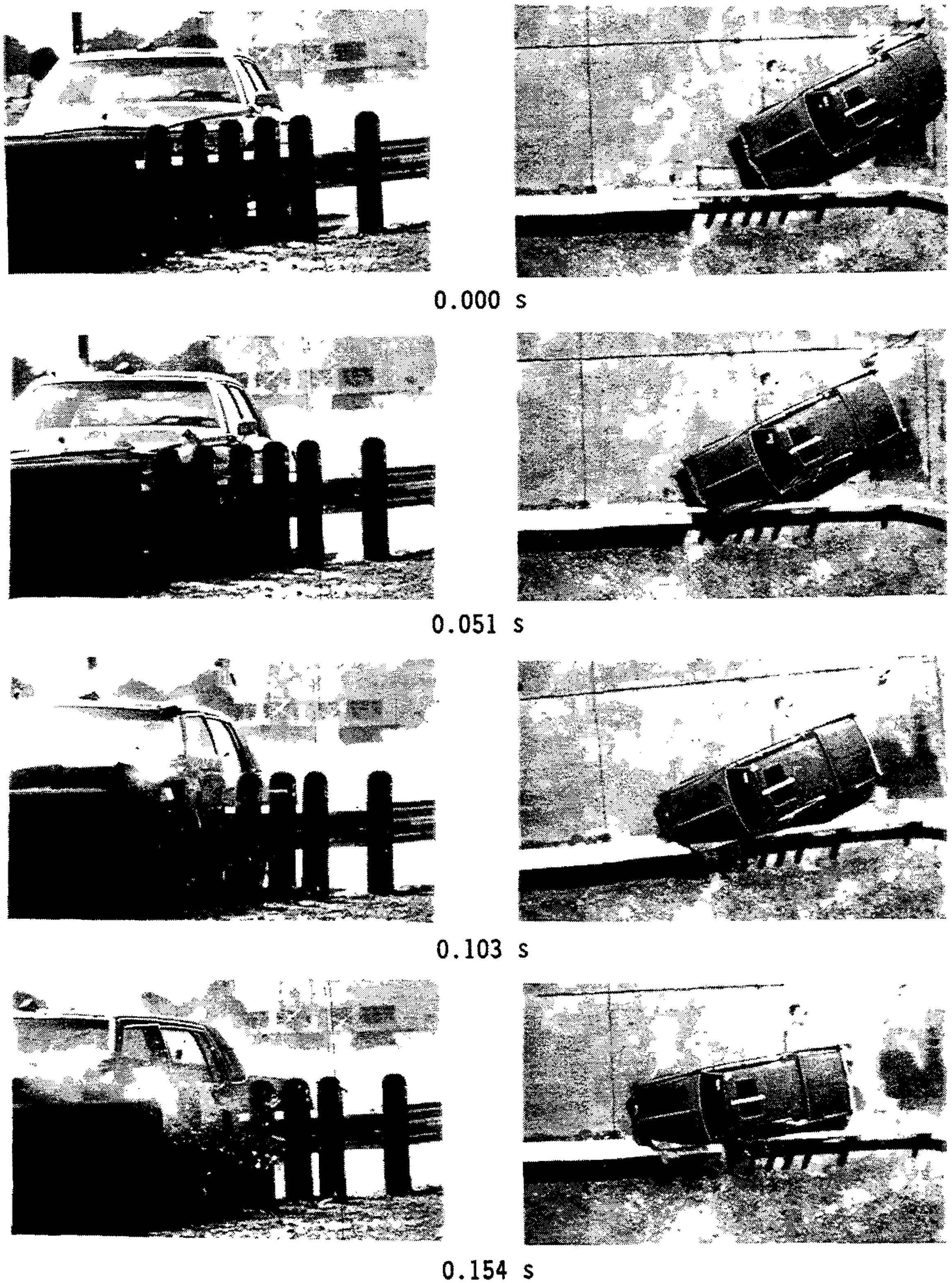
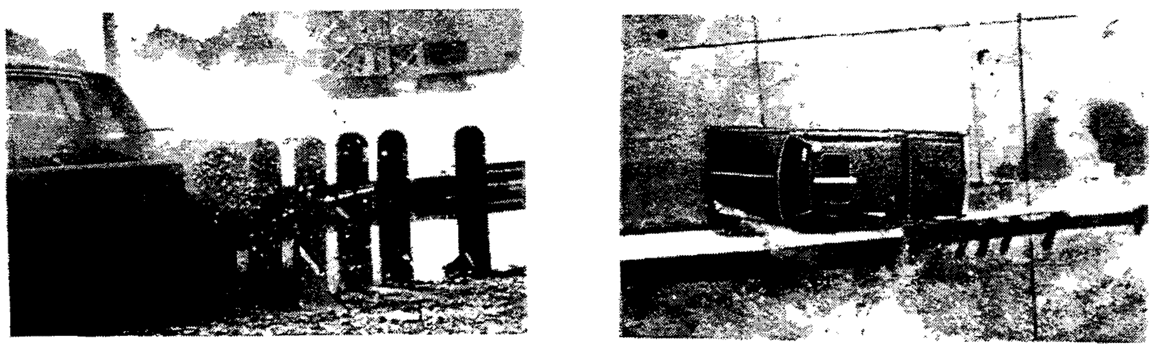
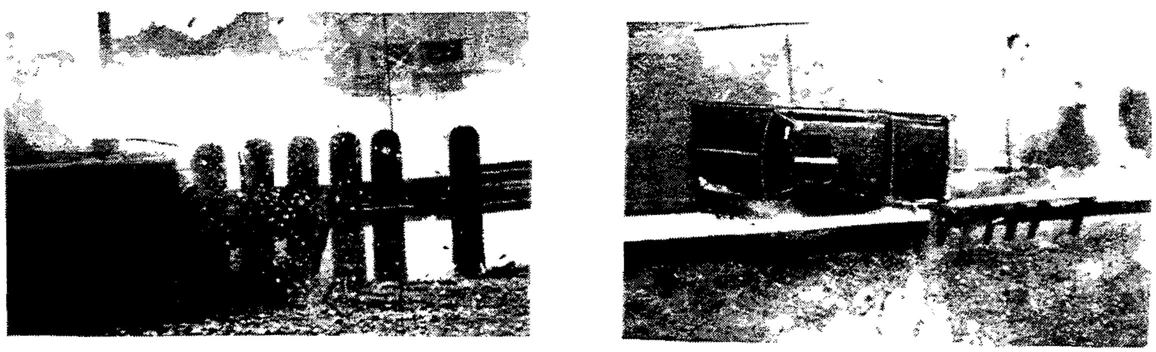


FIGURE F-70. Sequential Photographs for Test 1263-4 (Frontal and Overhead)

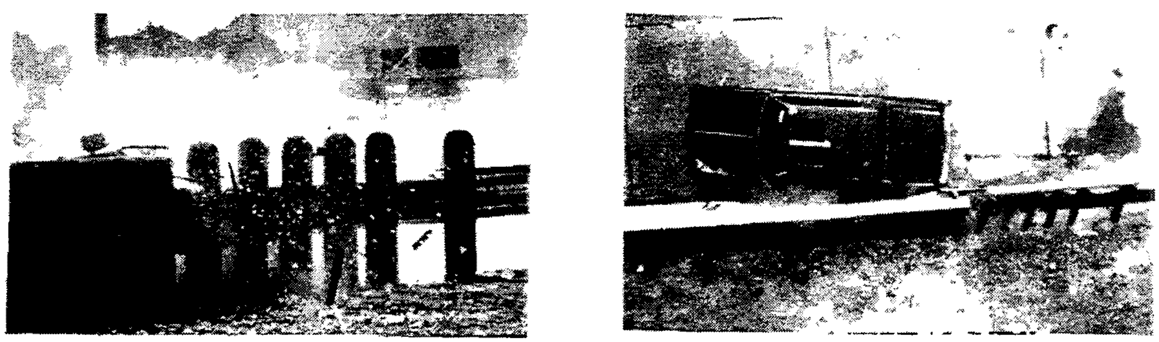
0.206 s



0.257 s



0.309 s



0.360 s

FIGURE F-70. Sequential Photographs for Test 1263-4 (Frontal and Overhead) (continued)

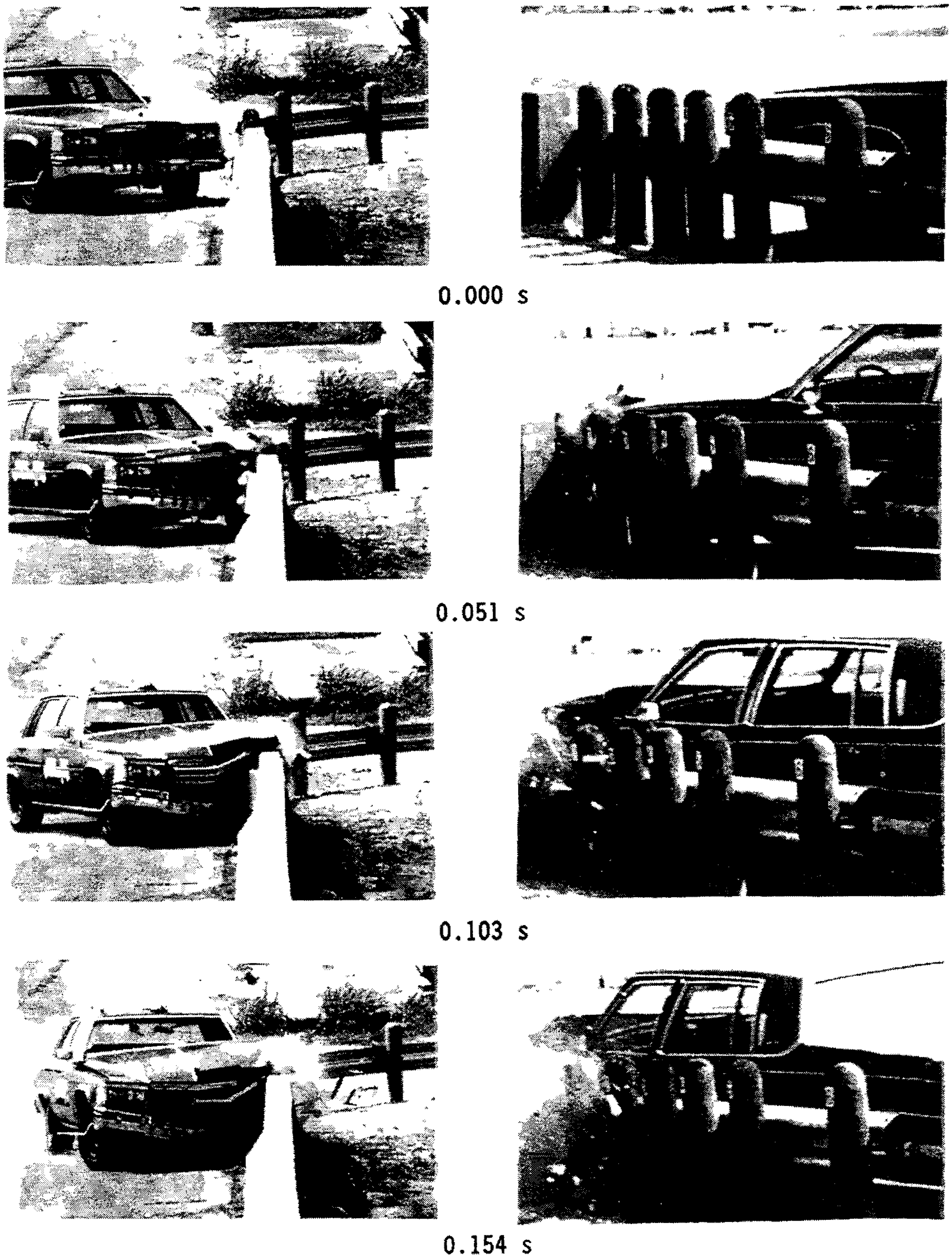
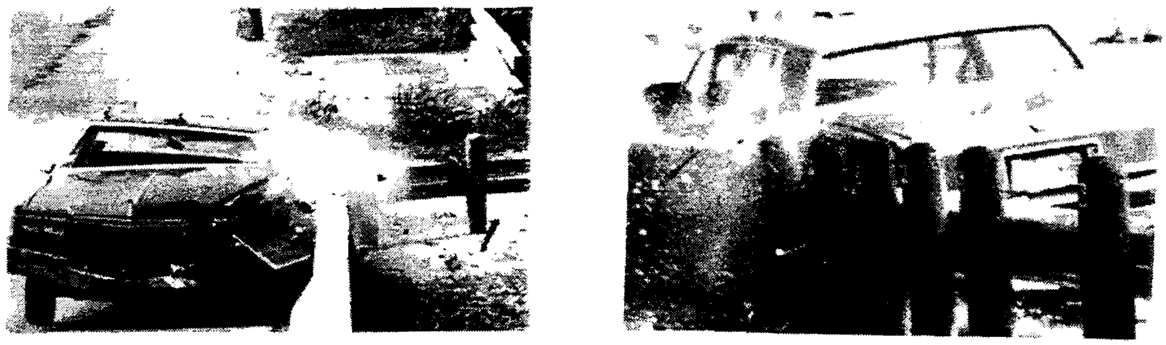
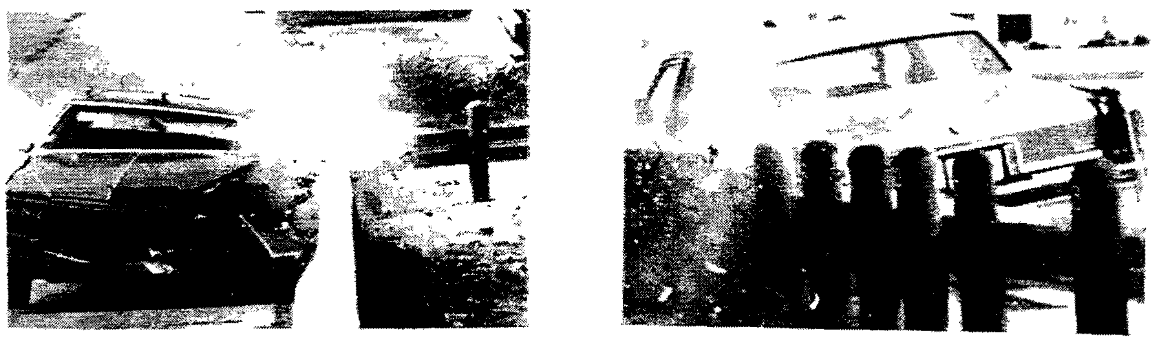


FIGURE F-71. Sequential Photographs for Test 1263-4 (Side Views)

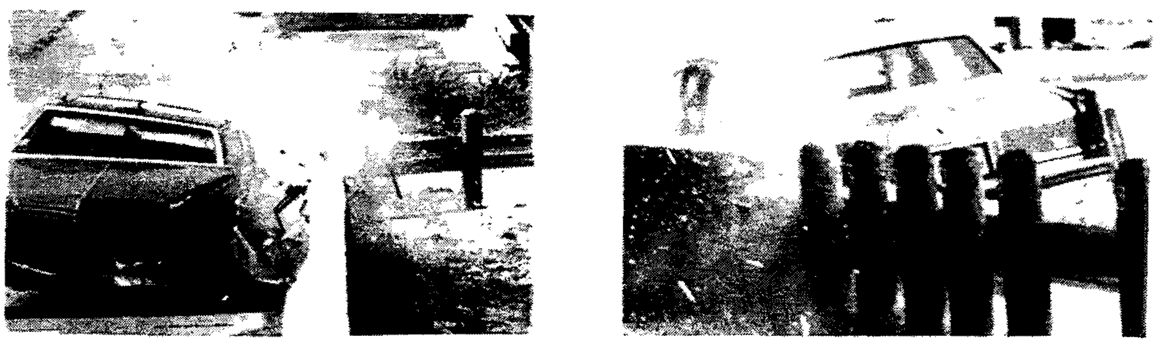
0.206 s



0.257 s



0.309 s



0.360 s

FIGURE F-71. Sequential Photographs for Test 1263-4 (Side Views) (continued)

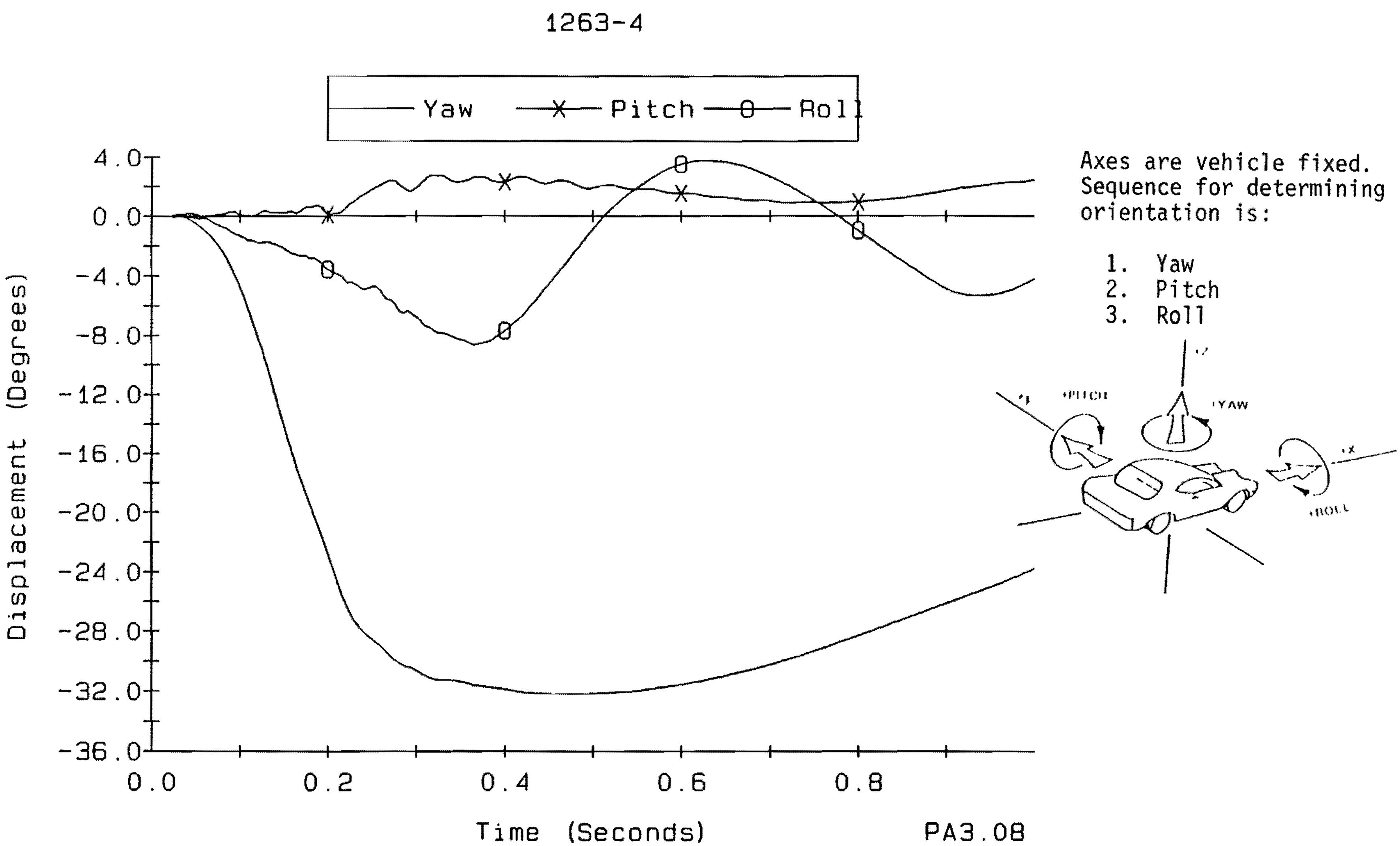


FIGURE F-72 Vehicle Angular Displacements for Test 1263-4

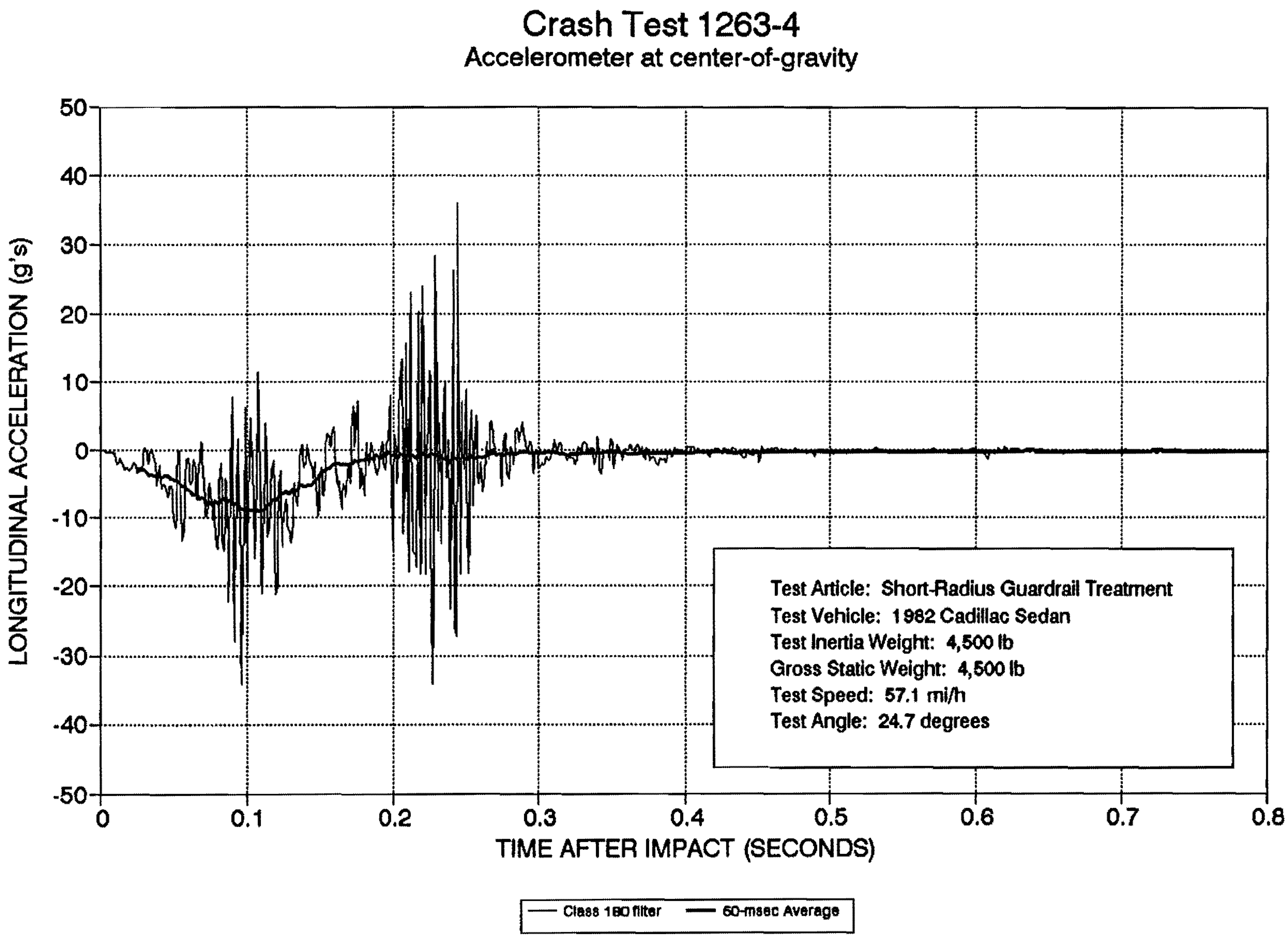


FIGURE F-73. Longitudinal Accelerometer Trace for Test 1263-4

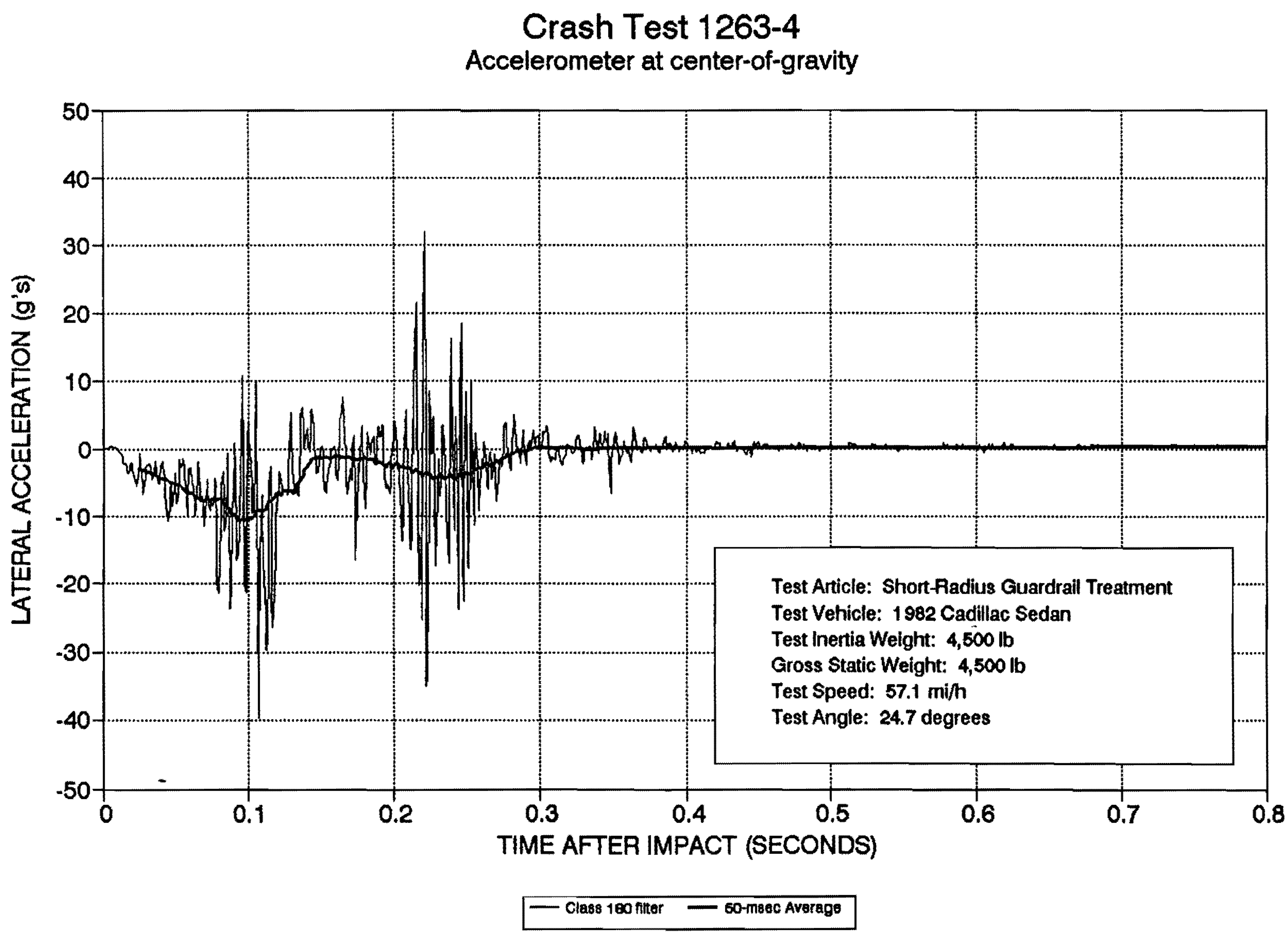


FIGURE F-74. Lateral Acceleration Trace for Test 1263-4

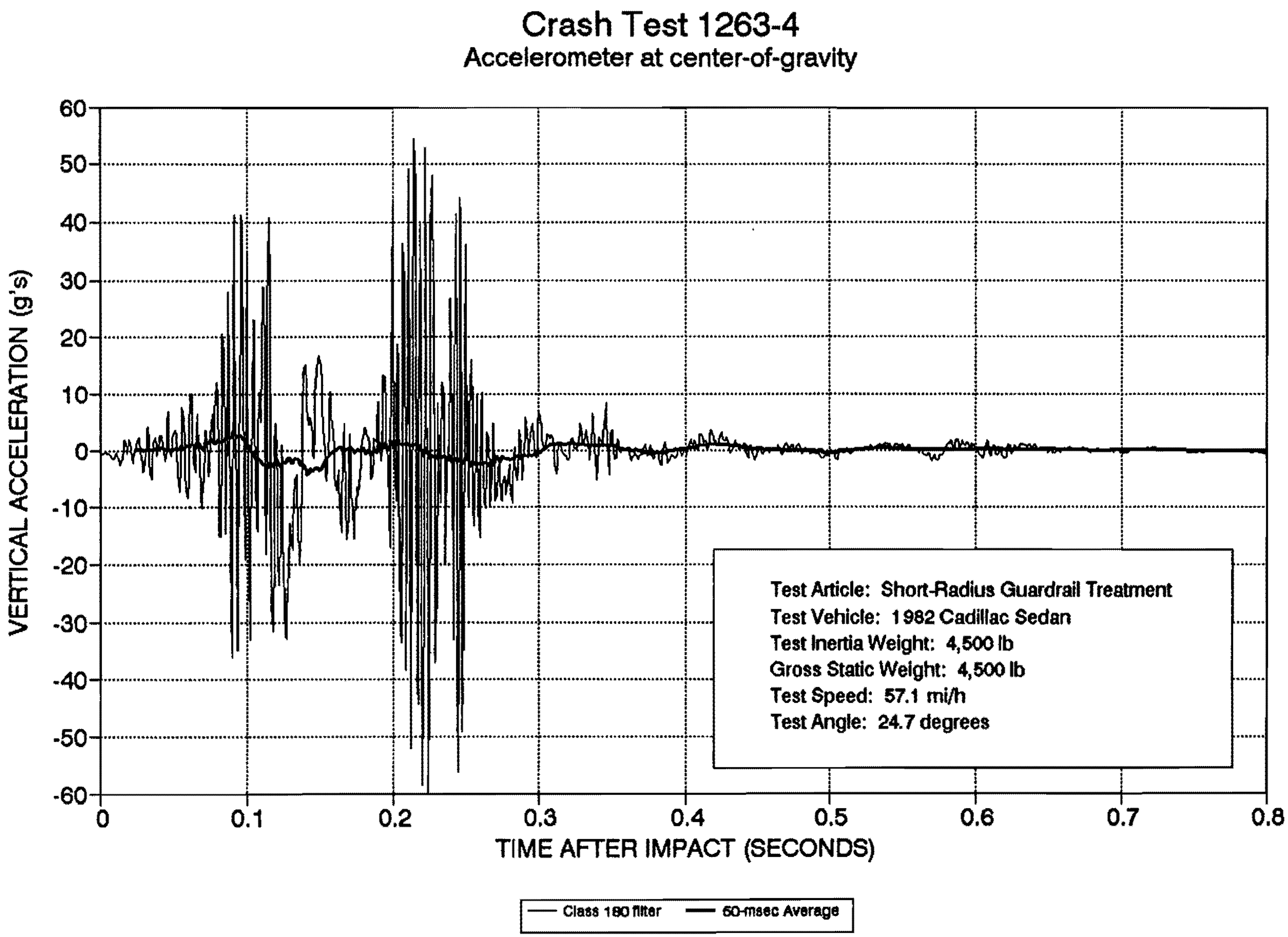


FIGURE F-75. Vertical Acceleration Trace for Test 1263-4

This test was judged to be a success. The installation successfully contained and redirected the test vehicle. Although not a requirement for evaluation of a structural adequacy test, all occupant risk criteria were below the maximum allowable values recommended in NCHRP Report 230, further indicating that the vehicle was smoothly redirected without experiencing any severe decelerations. The vehicle remained stable both during impact and after exiting from the installation. Damage to the barrier and vehicle was minor for a test of this severity. There was no intrusion and only minimal deformation to the floor pan of the occupant compartment. Both the exit velocity and exit angle of the vehicle were below the recommended limits set forth in NCHRP Report 230.

Test 1263-5 (4,500 lb/58.5 mph/26.8 deg)

This test was a strength test which evaluated the structural adequacy of the short radius system for large car impacts into the curved portion of rail. In an effort to simplify fabrication and construction of the system, the radius of the curved portion of rail was increased from 14 ft-3 in. to 16 ft-0 in. for this test. With a 16 ft radius, the curved section of guardrail begins and ends at a post location and has interchangeable pieces of rail at either end of the curve. This modification decreased the stiffness of the curved region and, therefore, it was determined that the small car test did not have to be rerun since the previous configuration was more critical in terms of occupant severity. A 1982 Cadillac Coupe DeVille (Figure F-76) was used for this test. The completed test installation is shown in Figure F-77. Test inertia mass of the vehicle was 4,500 lb (2041 kg) and its gross static mass was 4,500 lb (2,041 kg). The height to the lower edge of the bumper was 12.0 in. (30.5 cm), and the height to the upper edge of the bumper was 20.25 in. (51.4 cm). Additional dimensions and other information pertaining to the test vehicle are listed in Figure F-78. The vehicle was directed into the guardrail as shown in Figure F-79 using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. The vehicle impacted the midpoint of the curved segment of guardrail travelling at a speed of 58.5 mph (94.1 km/h) and at an angle of 26.8 degrees relative to the tangent section of guardrail along the primary roadway.

Upon impact, the bumper engaged the lower corrugation of the nested W-beam rail and, as the rail deflected, the weakened posts fractured as designed. The system was decelerating the vehicle and working as expected when the bumper of the vehicle appeared to rotate. Shortly

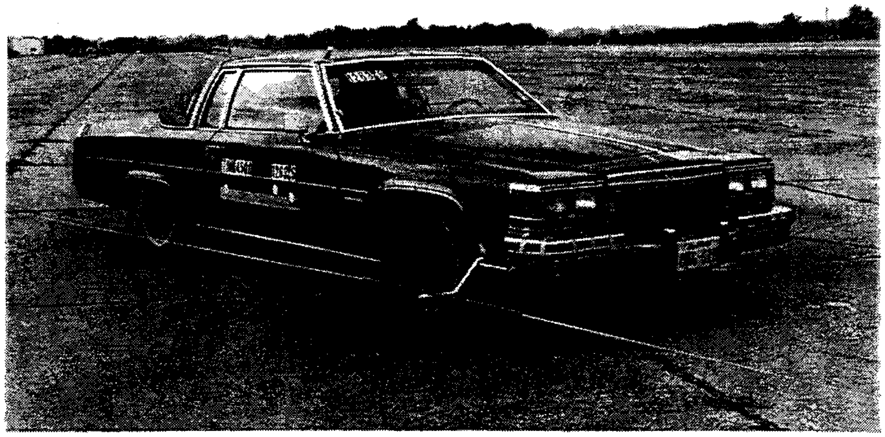


FIGURE F-76. Vehicle Prior to Test 1263-5

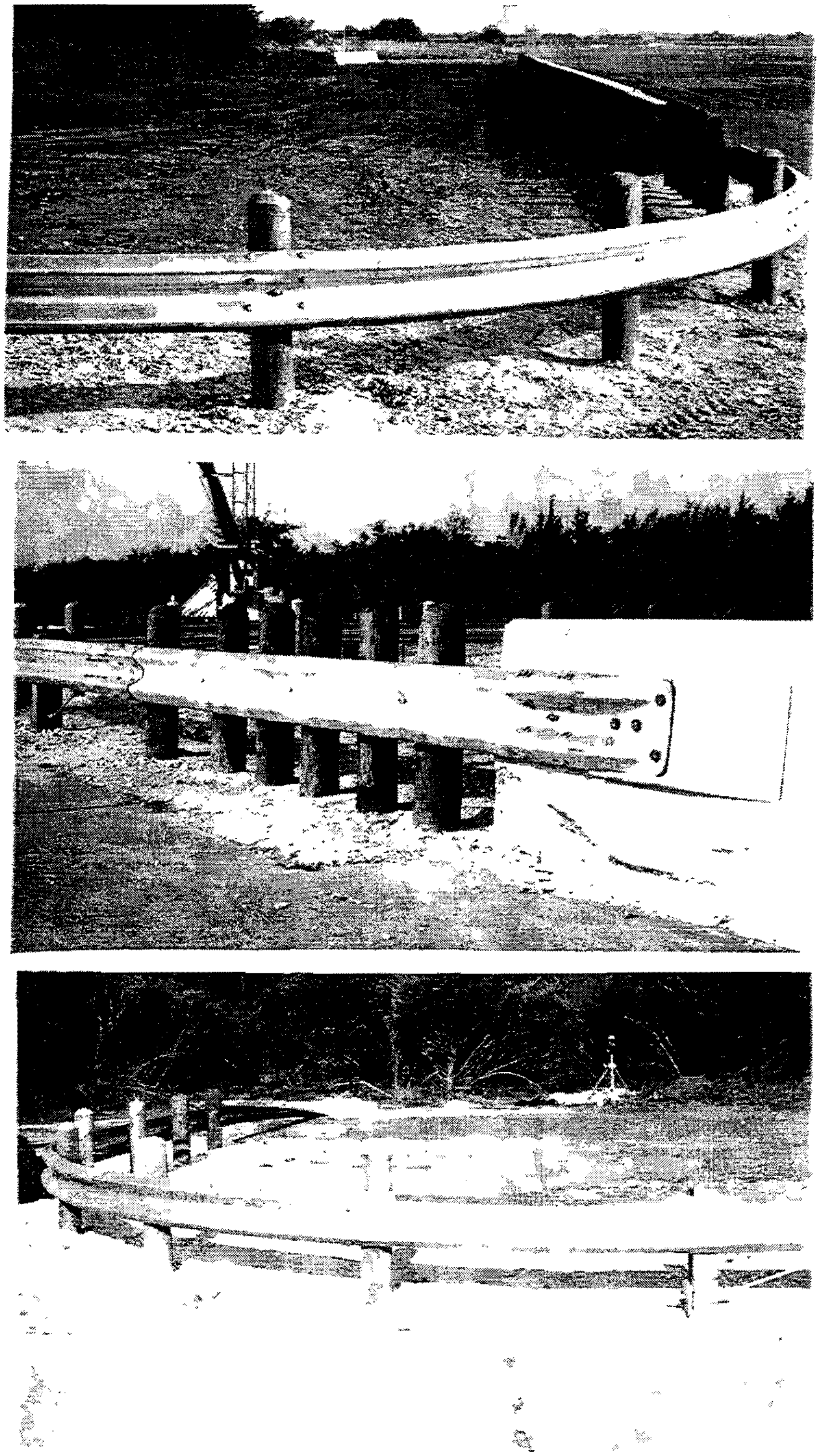


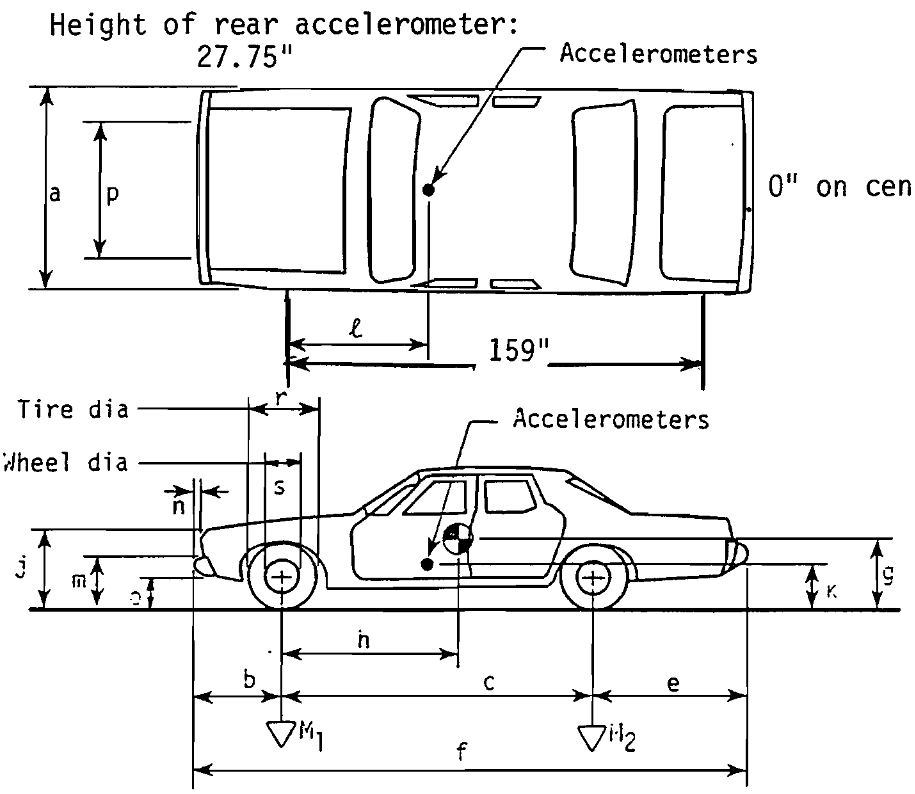
FIGURE F-77. Short Radius Guardrail before Test 1263-5

Date: 8-25-92 Test No.: 1263-5 VIN: G6AD4787C9163906

Make: Cadillac Model: Coupe de Ville Year: 1982 Odometer: 98758

Tire Size: P215 75R15 Ply Rating: ____ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___ fair ___ badly worn X



Vehicle Geometry - inches

a	77"	b	40.5"
c	121"	d*	54.5"
e	54"	f	215.5"
g		h	56.7"
i	----	j	33.5"
k	15.75"	ℓ	51.5"
m	20.25"	n	4.25"
o	12"	p	61.5"
r	27.5"	s	16.25"

Engine Type: V-8

Engine CID: 4.1 L

Transmission Type:

Automatic ~~or Manual~~

~~FWD~~ RWD ~~4WD~~

Body Type: 2 Door

Steering Column Collapse Mechanism:

- ___ Behind wheel units
- ___ Convoluted tube
- ___ Cylindrical mesh units
- ___ Embedded ball
- ___ NOT collapsible
- ___ Other energy absorption
- ___ Unknown

Brakes:

Front: disc X drum ___

Rear: disc ___ drum X

4-wheel weight for c.g. det. ℓf 1226 rf 1165 ℓr 1069 rr 1040

Mass - pounds	Curb	Test Inertial	Gross Static
M_1		2391	
M_2		2109	
M_T		4500	

Note any damage to vehicle prior to test:

Crack in windshield (marked)

*d = overall height of vehicle

FIGURE F-78. Test Vehicle Properties (1263-5)

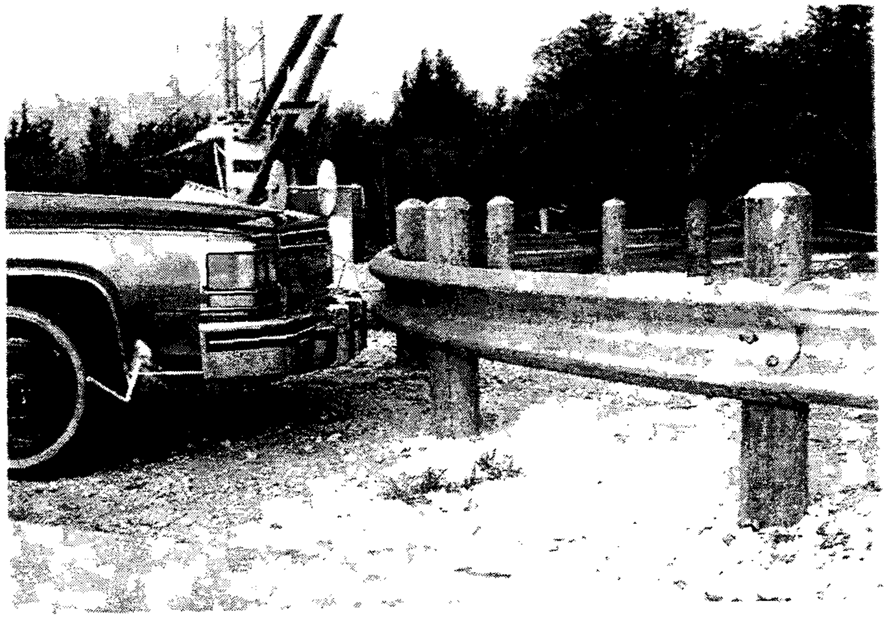


FIGURE F-79. Vehicle/Guardrail Geometrics for Test 1263-5 thereafter, the guardrail rode up and over the engine compartment and engaged the windshield and roof of the vehicle. When the car penetrated under the rail, it was travelling at a speed of 36.6 mi/h (58.9 km/h) and at an angle of 33.9 degrees with respect to the tangent section of guardrail. The vehicle came to rest 107 ft (32.6 m) from the point of impact in some brush behind the guardrail installation.

As shown in Figures F-80 and F-81, the guardrail received extensive damage. All of the weakened posts, namely posts 7 through 12, fractured at or below ground level. Standard posts 6, 13, and 14 had rotated in the soil and were leaning after the test. Posts 7, 9, 11, and 13 all separated from the guardrail. The positions of the rail at posts 6 through 11 were measured and recorded for specific times and are listed in Table F-5. The maximum dynamic deflection of 28.3 ft (8.6 m) occurred at post 9, and the maximum residual deformation was 25.4 ft (7.7 m).

As shown Figure F-82, the vehicle sustained extensive damage. Both the left and right front corners were crushed 15.0 in. (38.1 cm) at bumper height. The wheelbase on the driver's side was reduced by 1.75 in. (4.4 cm) and the doors on both sides were jammed. The hood was separated from the vehicle when the guardrail over-rode the engine compartment, and there was considerable damage to the roof. Additionally, the windshield was shattered and there was damage to the grill, radiator, fan and both front fenders.

Although not required for the evaluation of a strength test, data from the accelerometer located at the center-of-gravity were digitized for evaluation and occupant risk factors are reported for information purposes. In the longitudinal direction, occupant impact velocity was 20.3 ft/sec (6.2 m/sec) at 0.171 sec, the highest 0.010-second average ridedown acceleration was -7.57 g between 0.437 and 0.447 sec, and the maximum 0.050-second average acceleration was -5.6 g between 0.008 and 0.058 sec. Lateral occupant impact velocity was -6.2 ft/sec (1.9 m/sec) at 0.321 sec, the highest 0.010-second occupant ridedown acceleration was 2.3 g between 0.357 and 0.367 sec and the maximum 0.050-second average acceleration was 2.1 g between 0.087 and 0.137 sec. This data and other pertinent information from the test are summarized in Figure F-83. Sequential photographs of the impact are shown in Figures F-84 and F-85. Vehicular angular displacements are displayed in Figure F-86, and vehicular accelerations versus time traces, filtered at SAE J211 (Class 180), are presented in Figures F-87 through F-89.

Since the test vehicle penetrated under the guardrail and was not successfully contained, this test was considered to be a failure as per evaluation criteria A of NCHRP Report 230. It

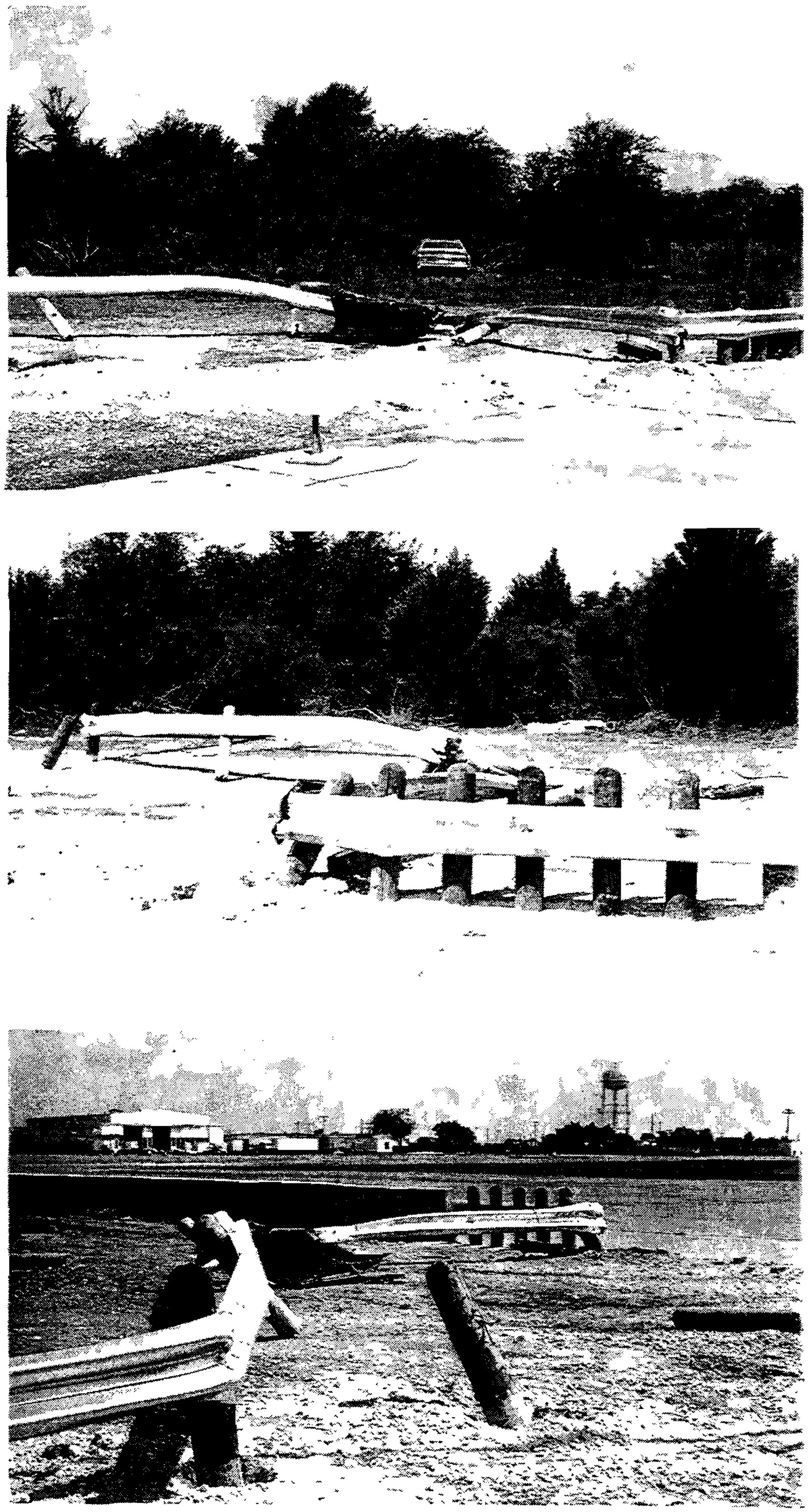


FIGURE F-80. Short Radius Guardrail after Test 1263-5

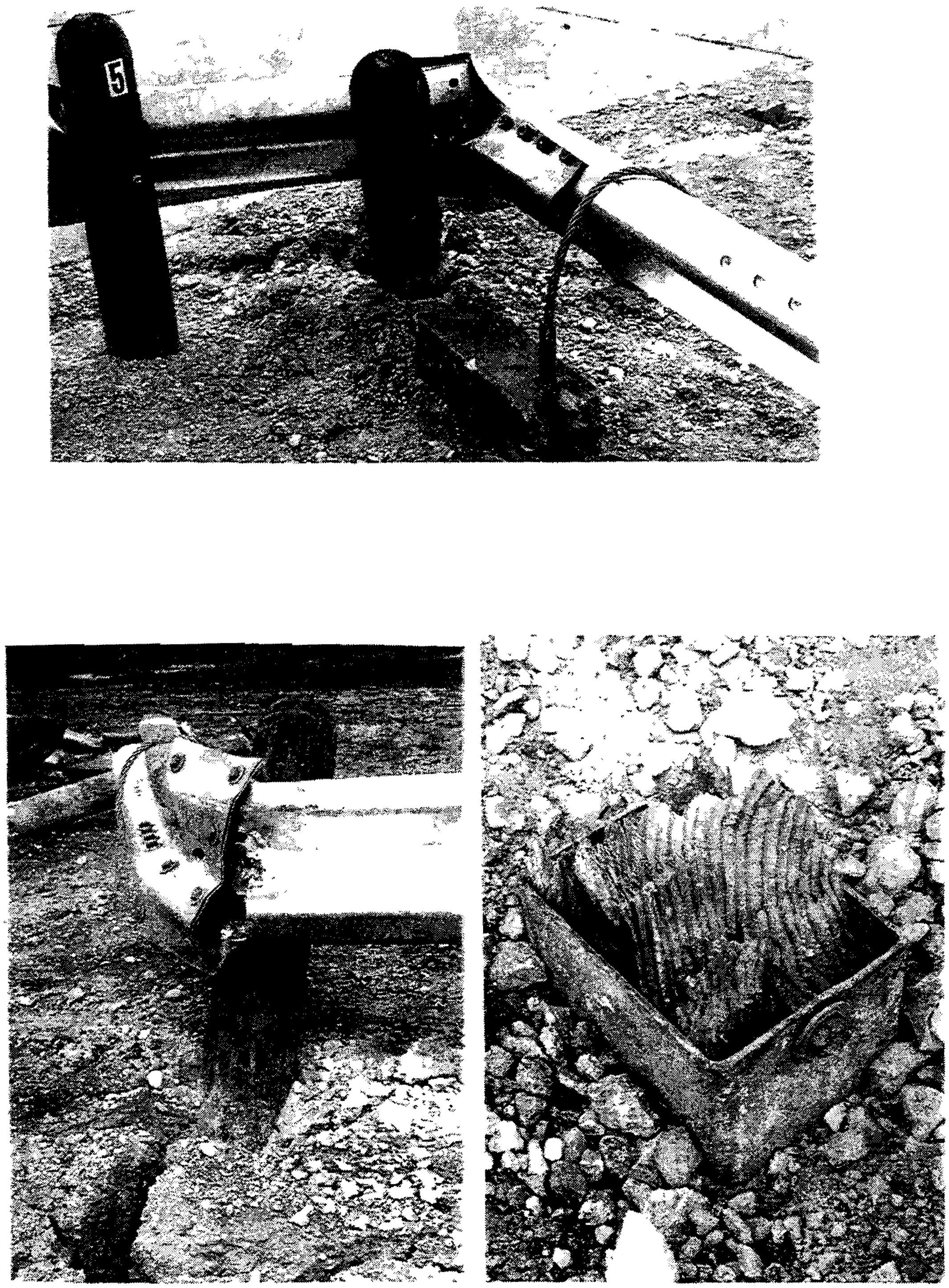


FIGURE F-81. Damage at Posts 5, 6, and 7, Test 1263-5

TABLE F-5. Rail Movements During Test 1263-5

Time	Post 6	Post 7	Post 8	Post 9	Post 10	Post 11
0	0	0	0	0	0	0
0.025	0.00	-0.23	-0.17	0.73	0.11	0.00
0.049	0.00	-0.21	0.22	2.88	1.03	-0.23
0.074	-0.05	-0.12	1.14	4.98	2.40	0.19
0.099	-0.04	0.10	1.99	6.67	3.89	0.40
0.123	-0.12	0.08	2.55	8.25	5.43	0.86
0.148	-0.13	0.03	4.39	9.83	6.53	1.75
0.173	-0.15	0.11	6.29	11.39	7.49	2.41
0.197	-0.15	0.30	7.99	13.04	8.91	3.16
0.222	-0.17	0.97	9.07	14.46	10.07	4.50
0.247	-0.18	1.90	10.14	16.02	11.45	5.91
0.271	-0.16	2.98	11.49	17.61	13.13	7.44
0.296	-0.18	4.29	12.91	18.99	14.67	9.08
0.321	-0.14	5.42	14.30	20.46	16.27	10.79
0.346	-0.18	6.82	15.69	21.79	17.86	12.14
0.370	-0.07	8.46	17.20	23.28	19.19	
0.395	0.12	9.55	18.34	24.39	20.69	
0.420	0.71	10.37	19.22	25.29	21.74	
0.444	1.11	10.81	19.74	25.51	22.62	
0.469	1.49	11.70	20.29	26.35		

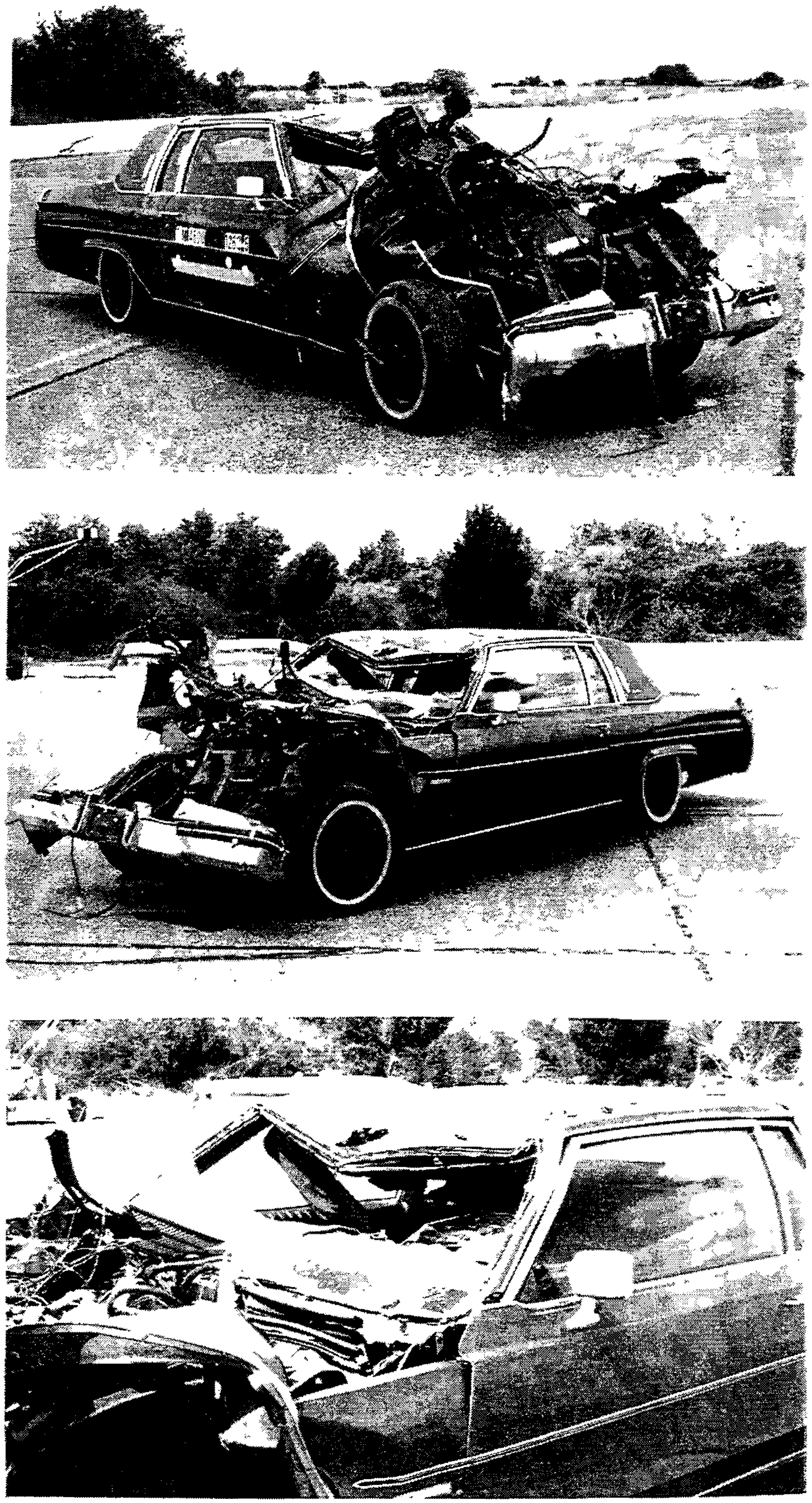
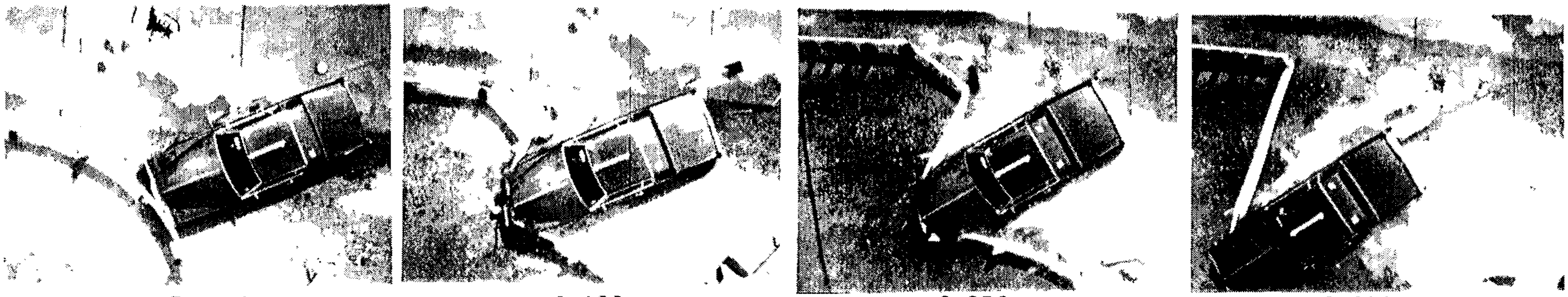
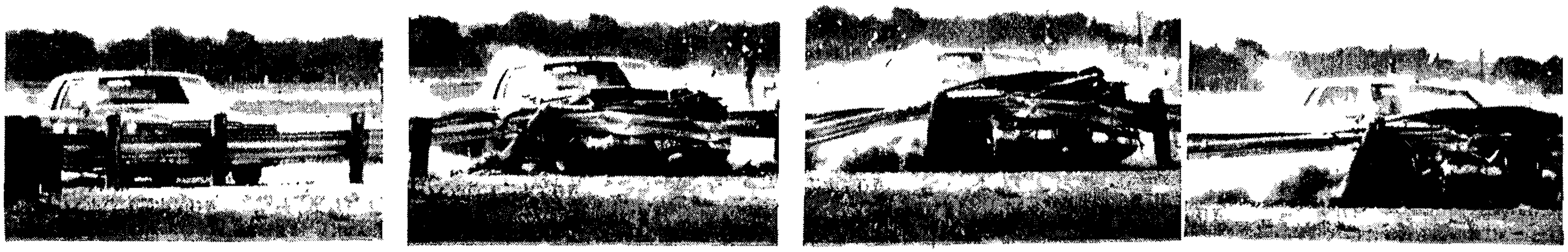


FIGURE F-82. Vehicle after Test 1263-5



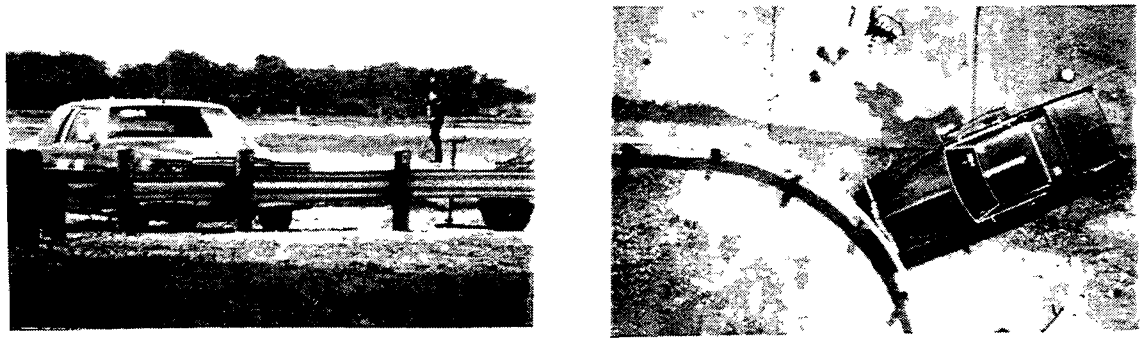
Impact 0.138 sec 0.276 sec 0.414 sec



Test No.	1263-5
Date	08/25/92
Test Installation . . .	Short-Radius Guardrail Treatment
Installation Length . .	100 ft (30 m)
Max. Dynamic Movement .	28.3 ft (8.6 m)
Max. Perm. Movement . .	25.4 ft (7.7 m)
Test Vehicle	1982 Cadillac Coupe
Vehicle Weight	
Test Inertia	4,500 lb (2,041 kg)
Gross Static	4,500 lb (2,041 kg)
Vehicle Damage Classification	
TAD	12FD7
CDC	12FCAW7
Maximum Vehicle Crush. .	15.0 in (38.1 cm)

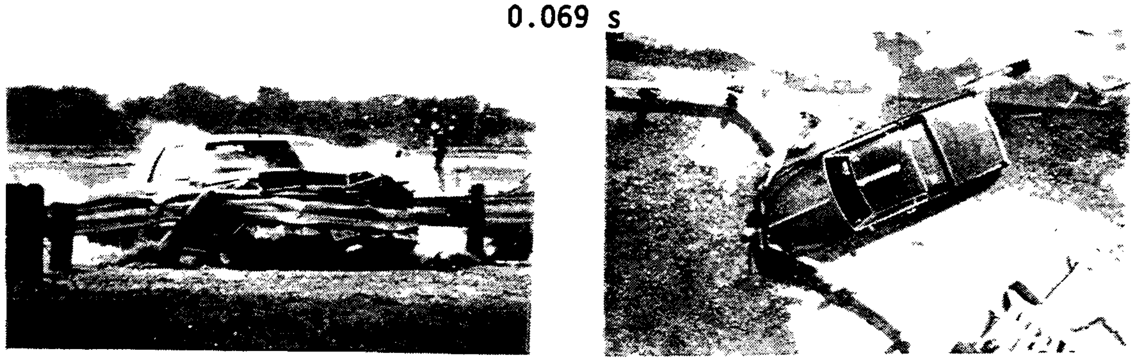
Impact Speed.	58.5 mi/h (94.1 km/h)
Impact Angle.	26.8 deg
Speed at Parallel . .	N/A
Exit Speed	36.6 mi/h (58.9 km/h)
Exit Trajectory . . .	Under the Guardrail
Vehicle Accelerations at center-of-gravity (Max. 0.050-sec Average)	
Longitudinal. . . .	-5.6 g
Lateral	2.1 g
Occupant Impact Velocity at true c.g.	
Longitudinal. . . .	20.3 ft/s (6.2 m/s)
Lateral	-6.2 ft/s (-1.9 m/s)
Occupant Ridedown Accelerations	
Longitudinal . . .	-7.6 g
Lateral	2.3 g

FIGURE F-83. Summary of Results for Test 1263-5

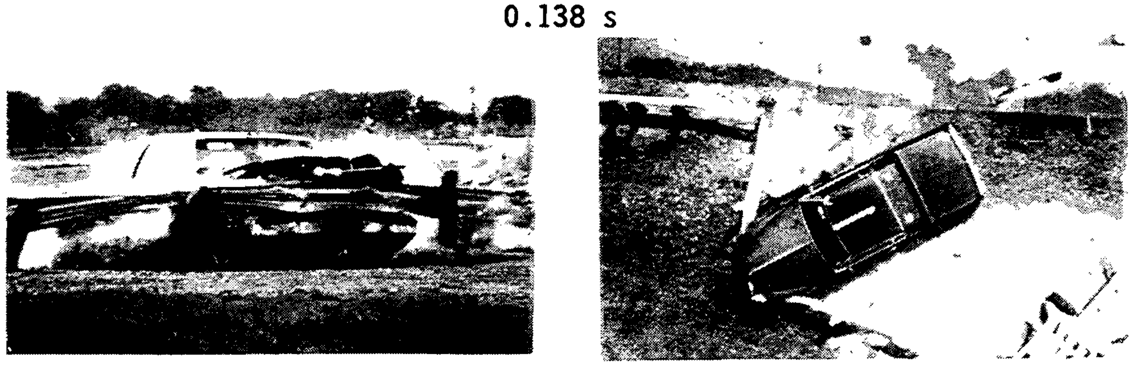


0.000 s

0.069 s

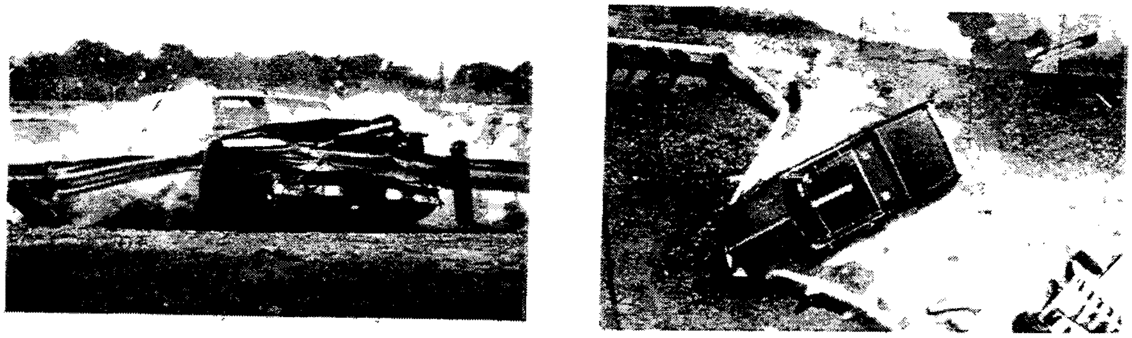


0.138 s



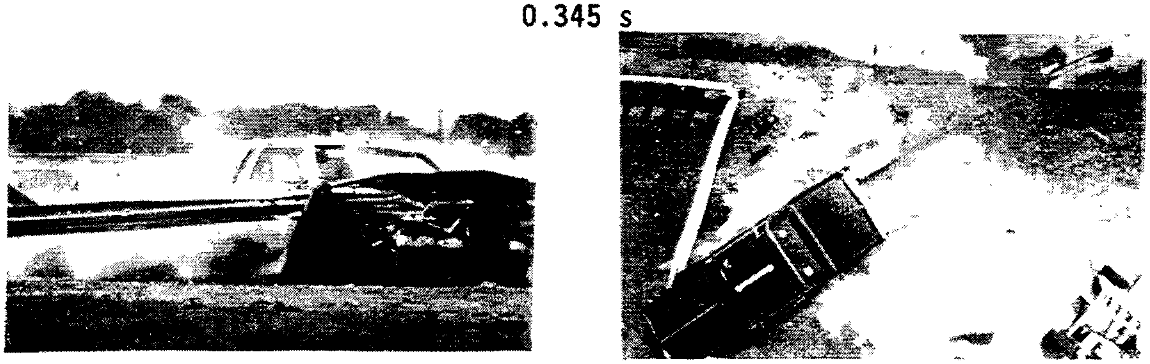
0.207 s

FIGURE F-84. Sequential Photographs for Test 1263-5 (Frontal and Overhead)

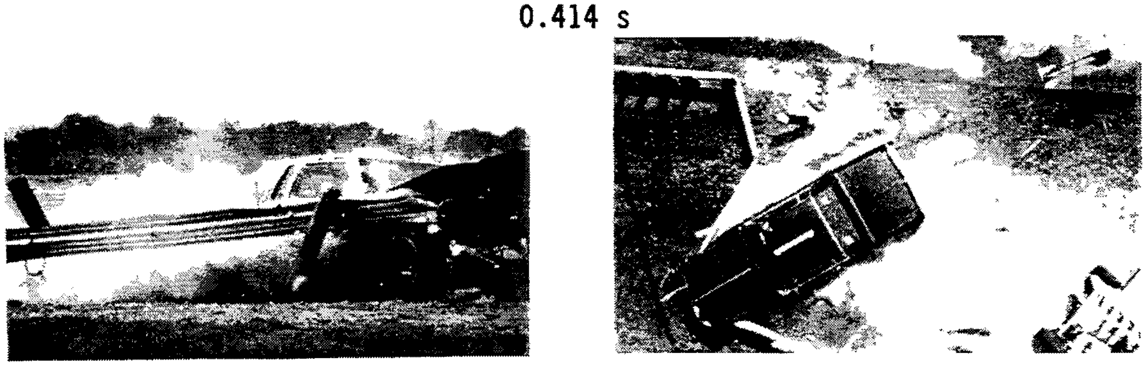


0.276 s

0.345 s



0.414 s

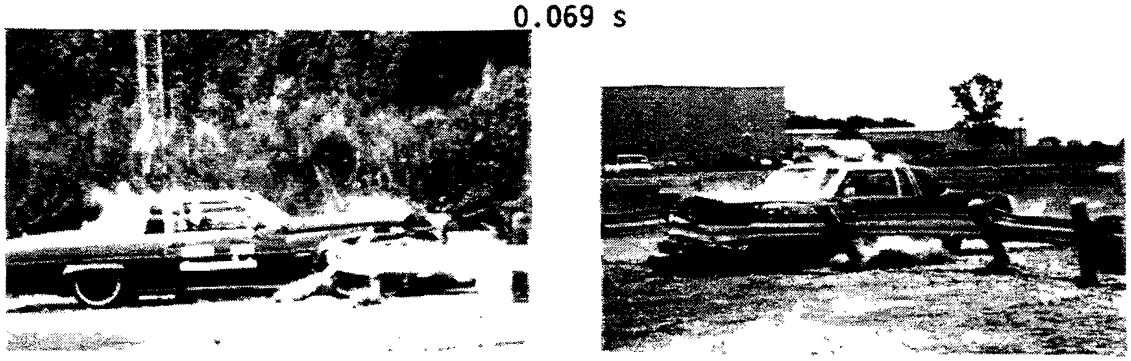


0.483 s

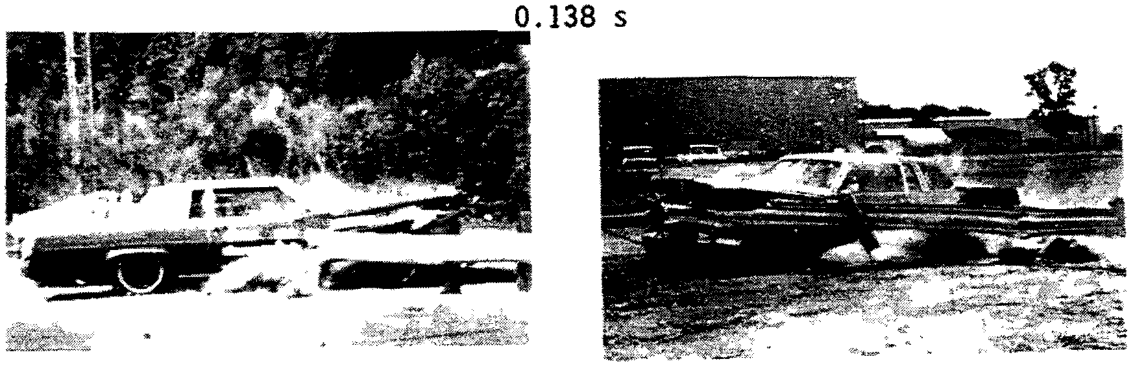
FIGURE F-84. Sequential Photographs for Test 1263-5 (Frontal and Overhead) (continued)

0.000 s

0.069 s

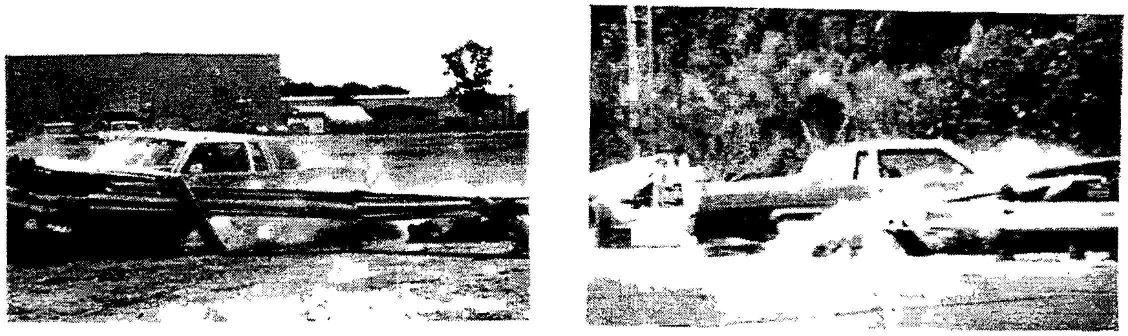


0.138 s



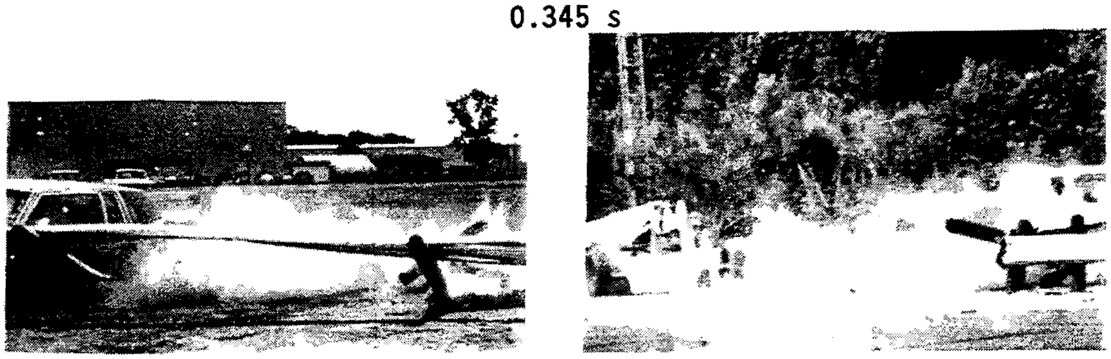
0.207 s

FIGURE F-85. Sequential Photographs for Test 1263-5 (Side Views)

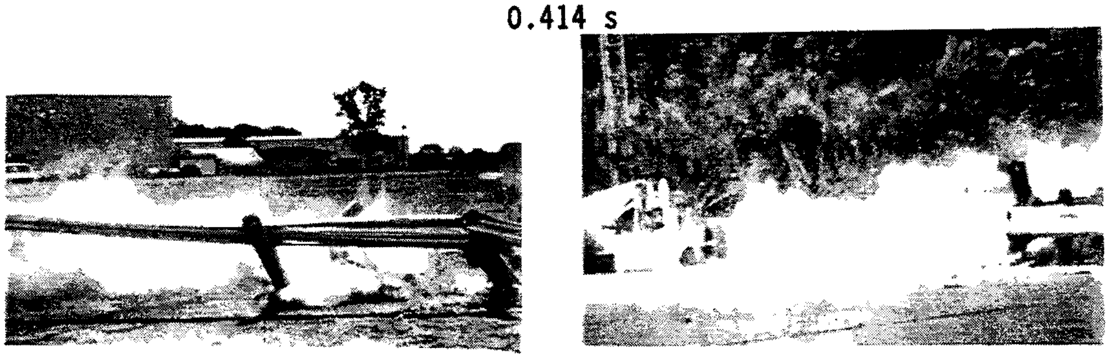


0.276 s

0.345 s

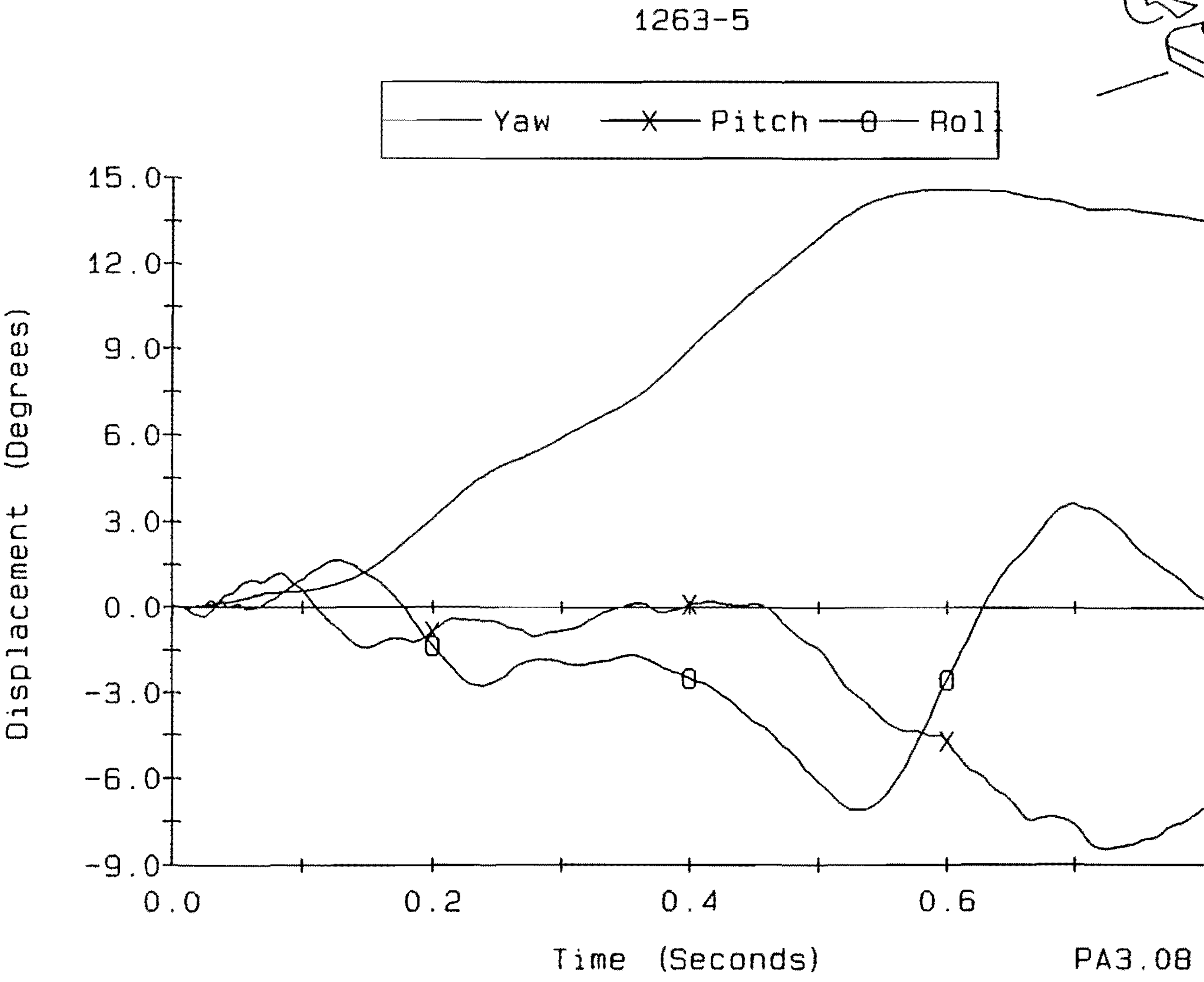


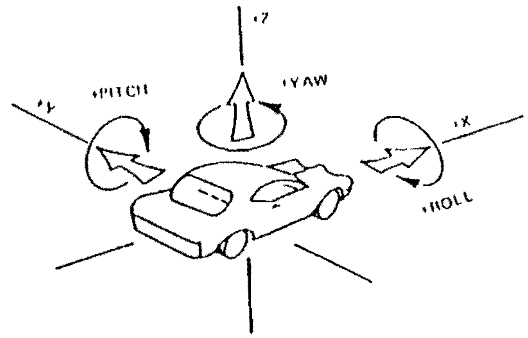
0.414 s



0.483 s

FIGURE F-85. Sequential Photographs for Test 1263-5 (Side Views) (continued)





Axes are vehicle fixed.
Sequence for determining
orientation is:

1. Yaw
2. Pitch
3. Roll

FIGURE F-86 Vehicle Angular Displacements for Test 1263-5

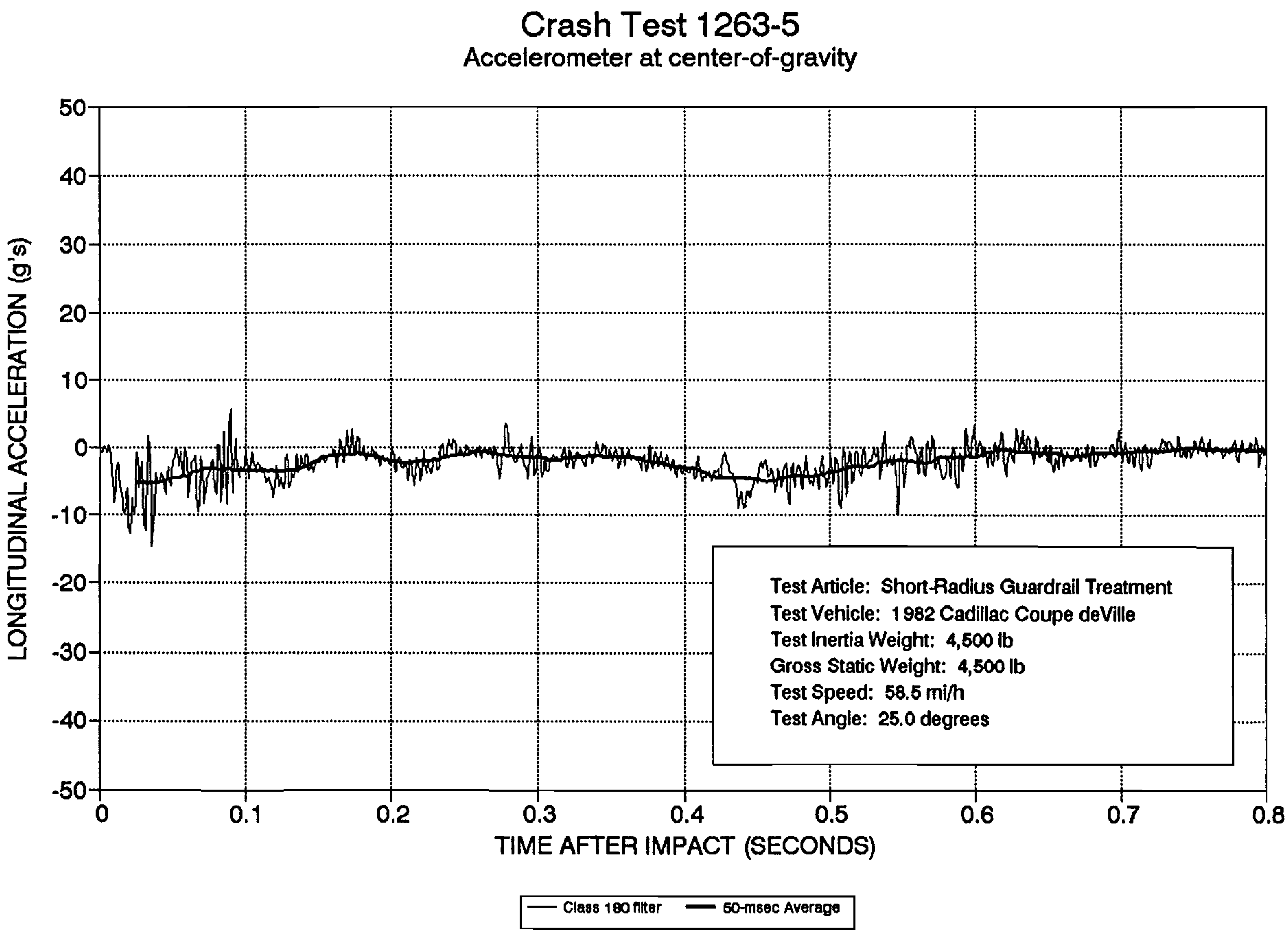


FIGURE F-87. Longitudinal Acceleration Trace for Test 1263-5

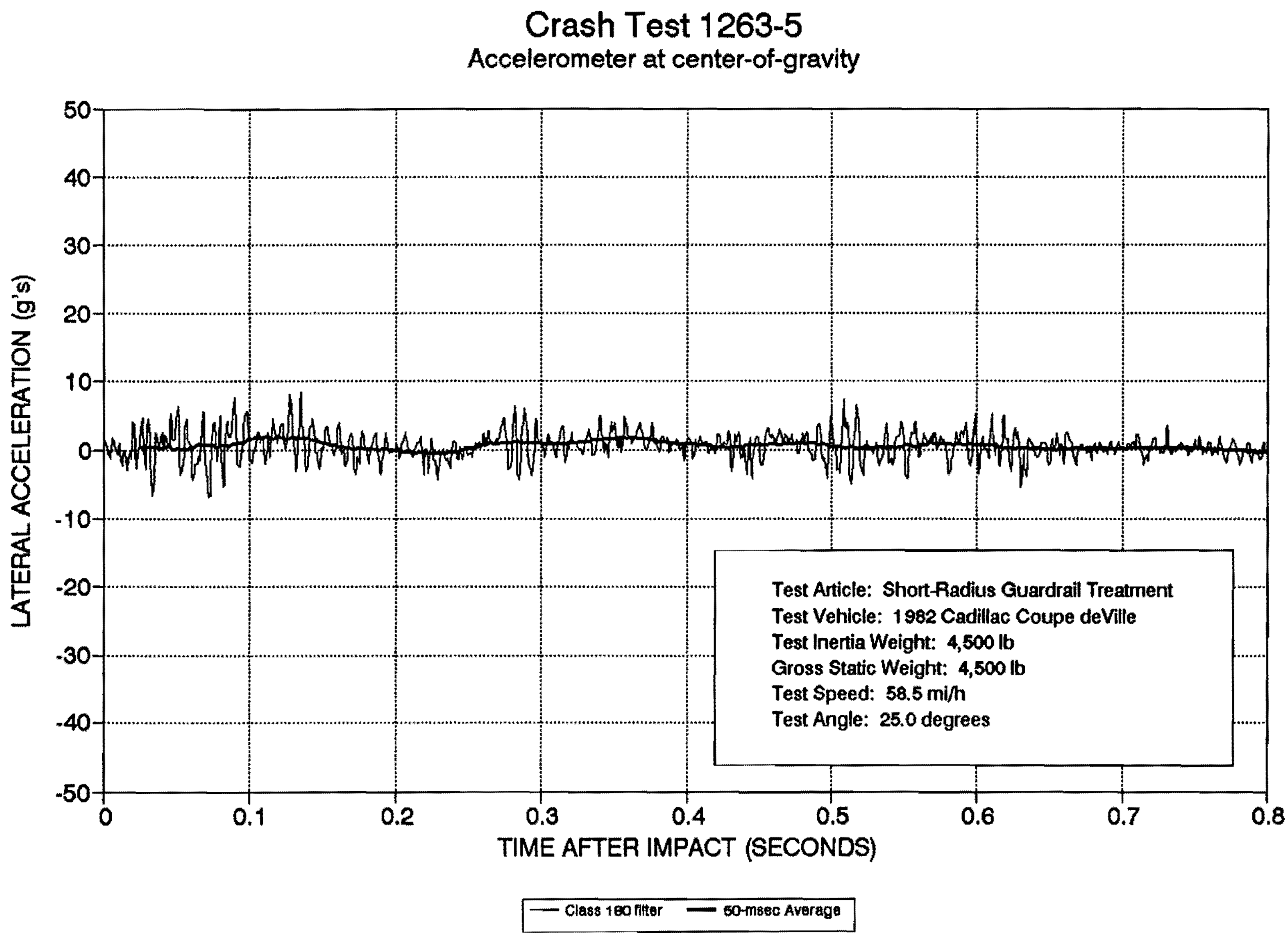


FIGURE F-88. Lateral Acceleration Trace for Test 1263-5

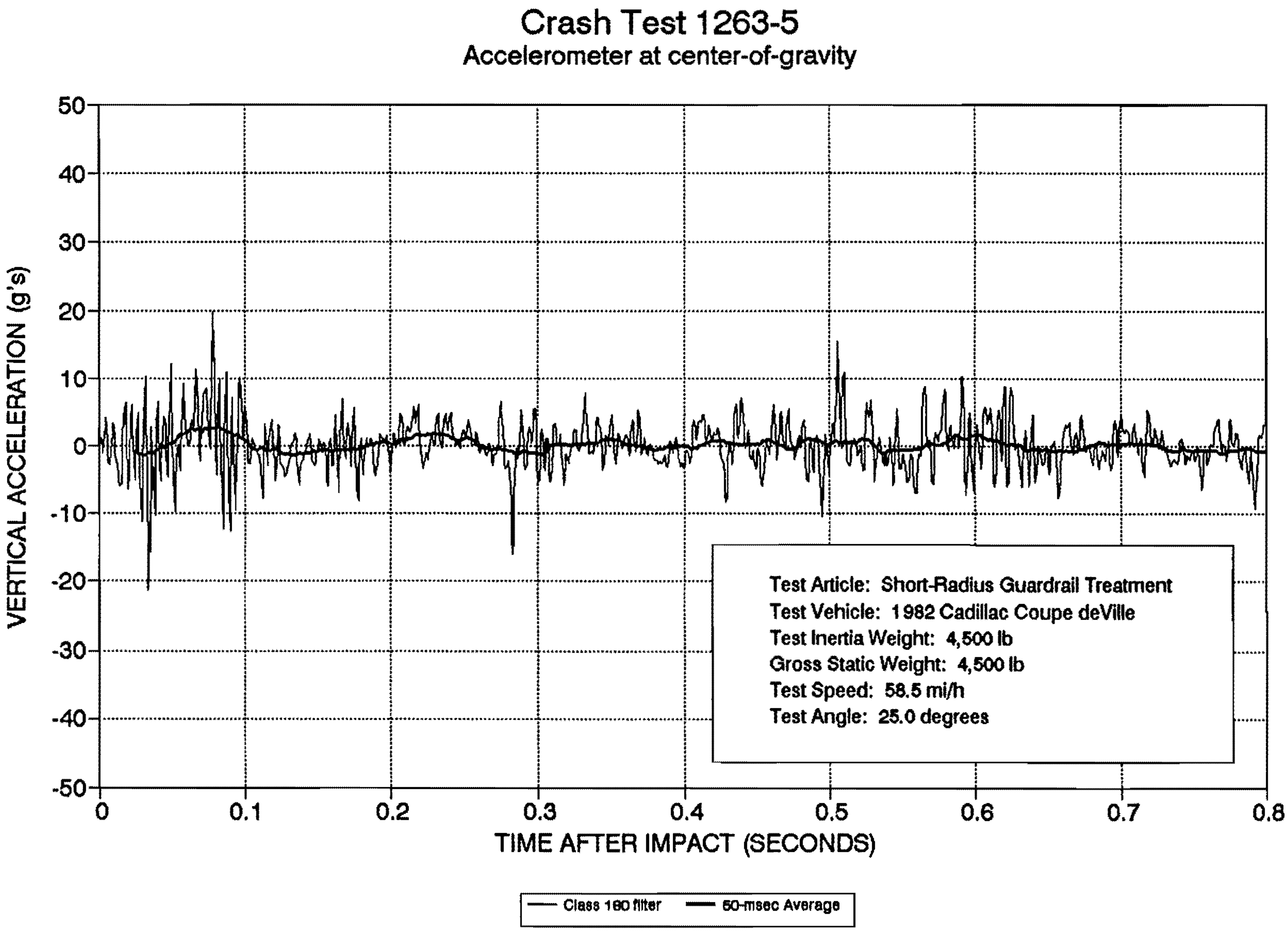


FIGURE F-89. Vertical Acceleration Trace for Test 1263-5

is uncertain how much the vehicle construction and the rotation of the bumper during the test contributed to the guardrail climbing over the engine compartment. However, up until the time of this occurrence, the system was smoothly decelerating the vehicle and had dissipated an amount of energy equivalent to a 45 mph impact.

Test 1263-6 (4,500 lb/58.3 mph/2.0 deg)

Due to the presence of the tubular W-beam, there was some concern about pocketing or spearing on the upstream end to the transition during shallow angle impacts into the curved section of the short radius treatment. The purpose of this test was, therefore, to evaluate the performance of the system under these conditions. A 1983 Cadillac Coupe DeVille (Figure F-90) was used for this crash test. The completed test installation is shown in Figure F-91. Test inertia mass of the vehicle was 4,500 lb (2041 kg) and its gross static mass was 4,500 lb (2,041 kg). The height of the bumper varied from 12.5 in. (31.8 cm) at its lower edge to 20.75 in. (52.7 cm) at its upper edge. Additional dimensions and other information pertaining to the test vehicle is shown in Figure F-92. The vehicle was directed into the guardrail as shown in Figure F-93 using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact. At the time of contact with the guardrail, the impact speed was 58.3 mi/h (93.8 km/h) and the angle was 2.0 degrees relative to the tangent section of guardrail.

The vehicle was smoothly contained and redirected by the short radius system. There were no indications of pocketing or spearing on the upstream end of the tubular W-beam. The vehicle lost contact with the rail 0.310 sec after impact travelling at a speed of 52.8 mi/h (84.9 km/h) and at an angle of 16.6 deg. After exiting the installation, the brakes were applied and the vehicle came to rest approximately 174 ft (53.0 m) from the point of first contact.

As shown in Figures F-94 through F-97, damage to the guardrail was minor in nature. There was slight displacement of the guardrail from post 6 to post 8. Post 8 was gouged approximately 5 in. (12.7 cm) to 7 in. (17.8 cm) above ground level and there was rubber transfer on both sides of the gouge. Post 7, the BCT anchor post, split longitudinally and fractured at its base.

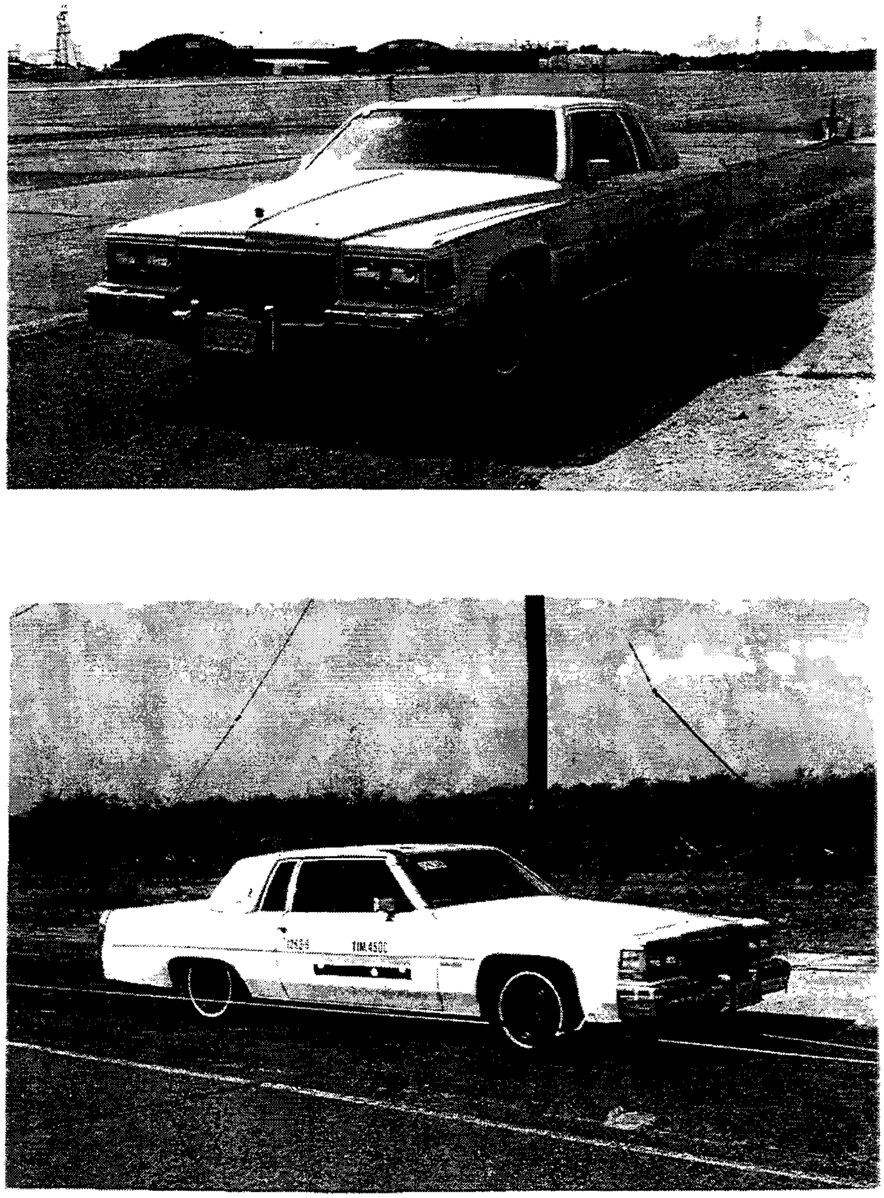


FIGURE F-90. Vehicle Prior to Test 1263-6

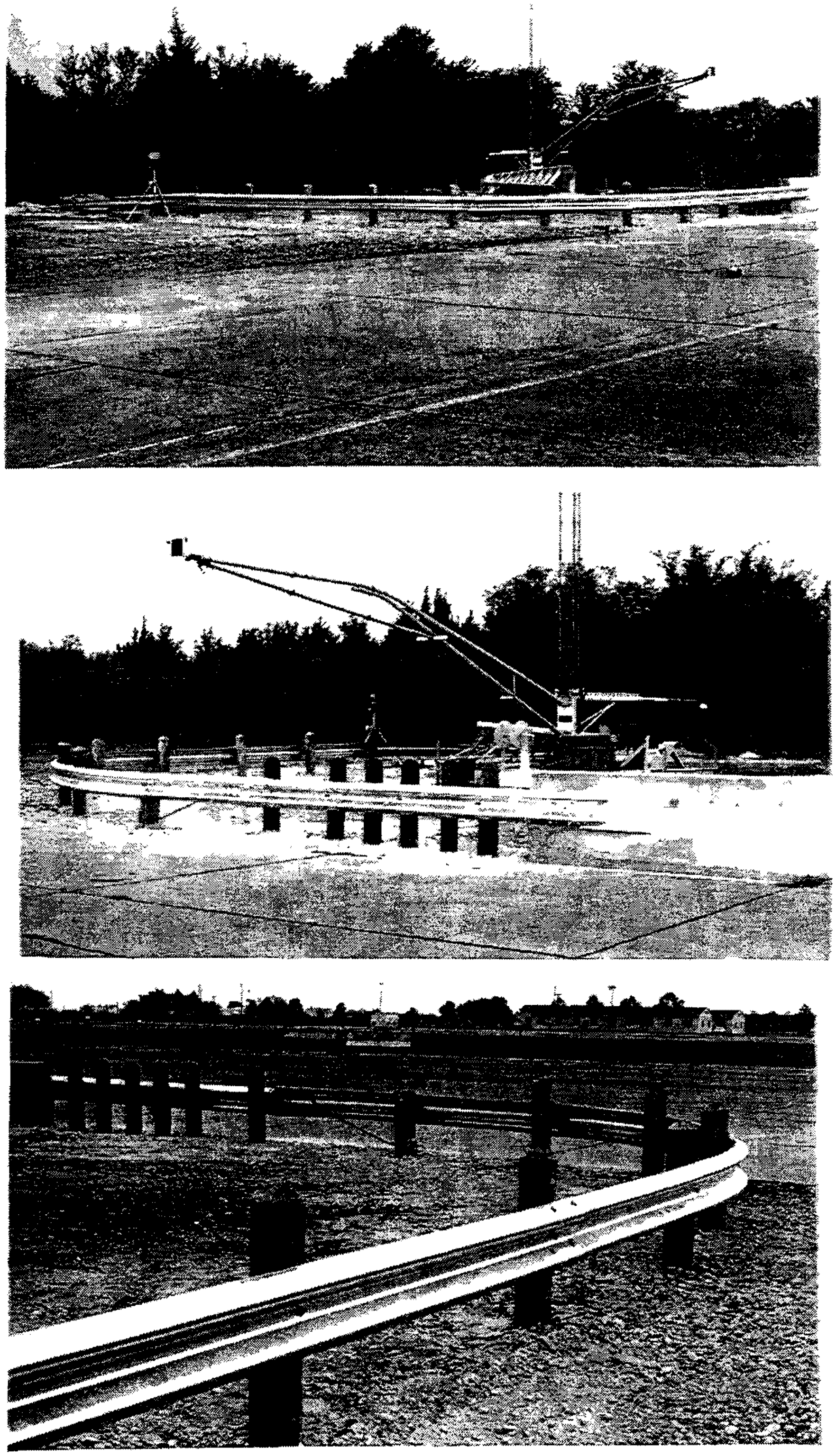


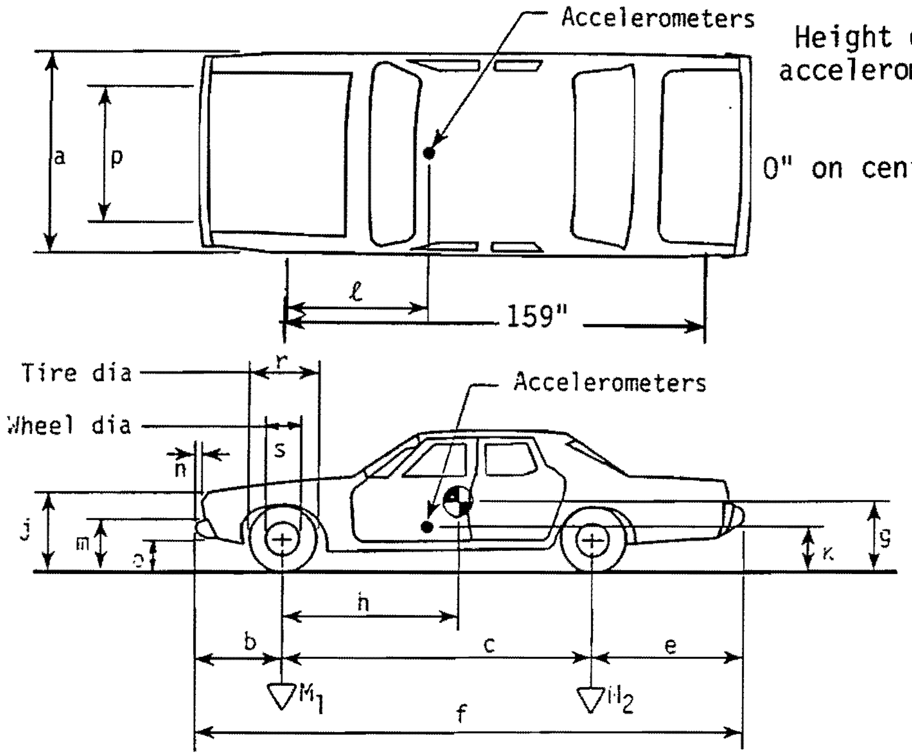
FIGURE F-91. Short Radius Guardrail before Test 1263-6

Date: 8-31-92 Test No.: 1263-6 VIN: 1G6AD4781D9150523

Make: Cadillac Model: Coupe de Ville Year: 1983 Odometer: 40317

Tire Size: p225/75R15 Ply Rating: ____ Bias Ply: ___ Belted: ___ Radial: X

Tire Condition: good ___
fair X
badly worn ___



Height of rear accelerometer: 29"

0" on center

Vehicle Geometry - inches

a	77"	b	41.25"
c	121"	d*	54.75"
e	56.75"	f	219"
g		h	59.5"
i	----	j	34"
k	17"	ℓ	52"
m	20.75"	n	4"
o	12.5"	p	62.5"
r	28"	s	16.25"

Engine Type: V-8

Engine CID: ____

Transmission Type:

Automatic XXXXXXXX

XXXXXXX RWD XXXXXXX

Body Type: 2 Door

Steering Column Collapse Mechanism:

__Behind wheel units
__Convoluted tube
__Cylindrical mesh units
__Embedded ball
__NOT collapsible
__Other energy absorption
__Unknown

Brakes:

Front: disc X drum ___

Rear: disc ___ drum X

4-wheel weight for c.g. det. ℓf 1163 rf 1123 ℓr 1129 rr 1085

Mass - pounds	Curb	Test Inertial	Gross Static
M_1	2324	2286	
M_2	1706	2214	
M_T	4030	4500	

Note any damage to vehicle prior to test:

*d = overall height of vehicle

FIGURE F-92. Test Vehicle Properties (1263-6)

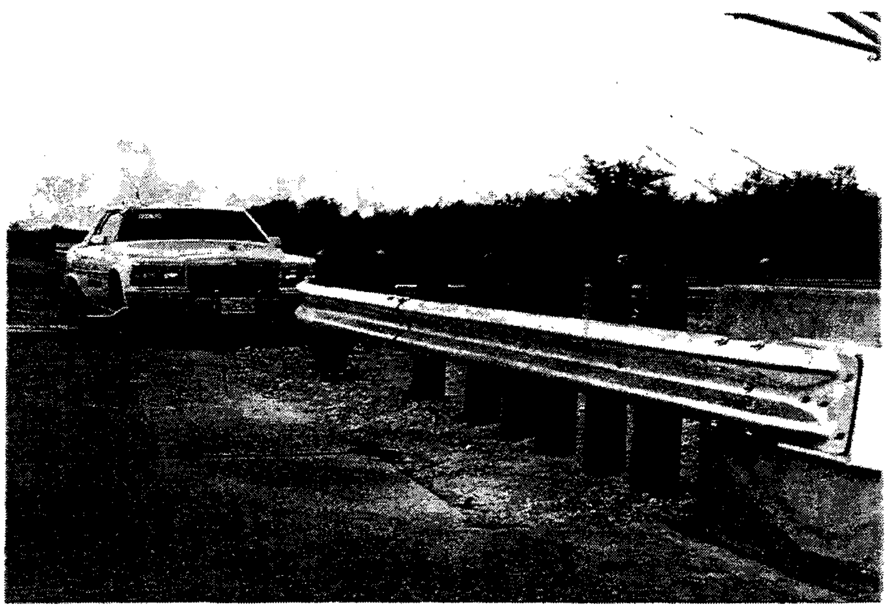


FIGURE F-93. Vehicle/Guardrail Geometrics for Test 1263-6

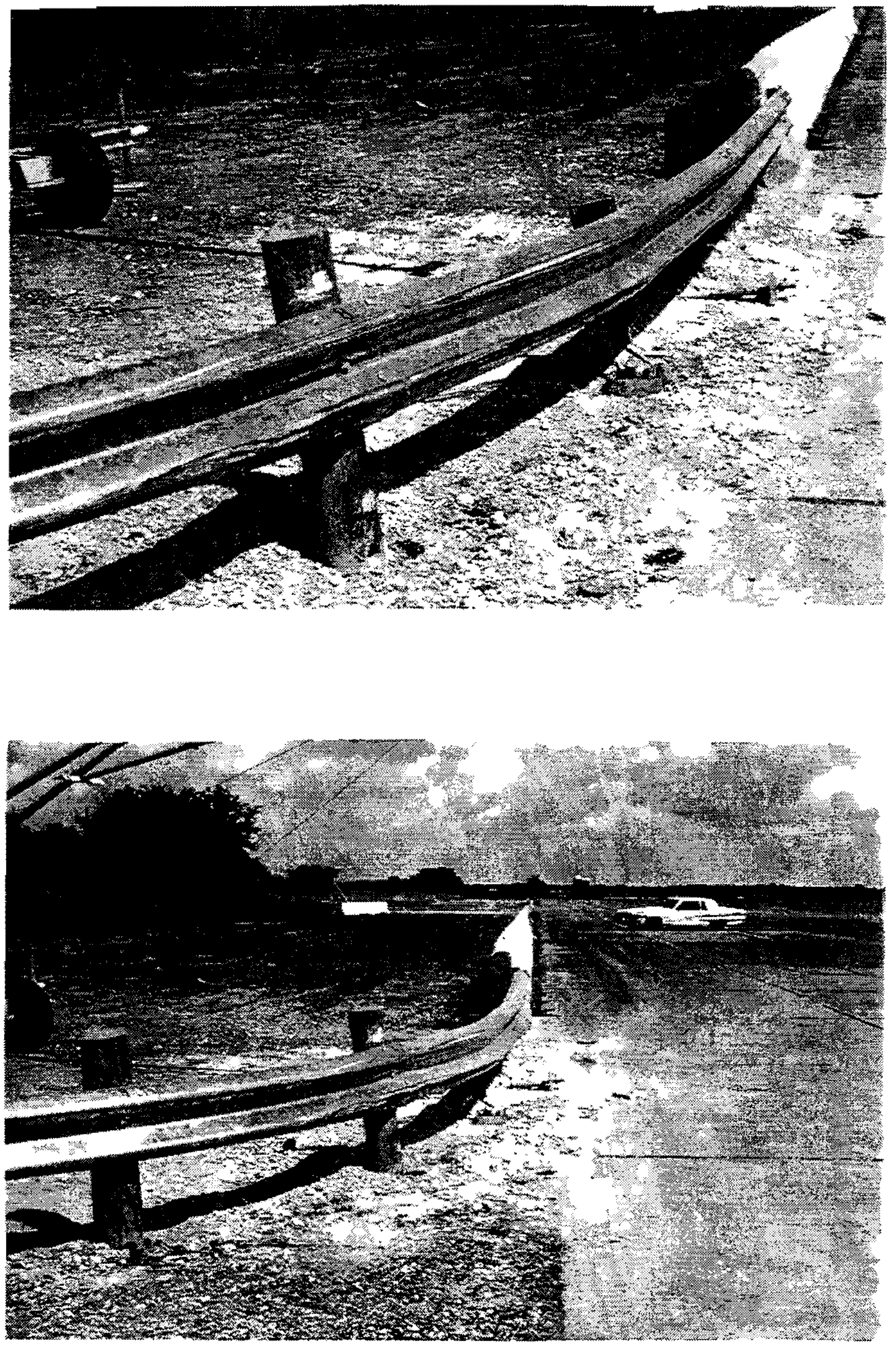
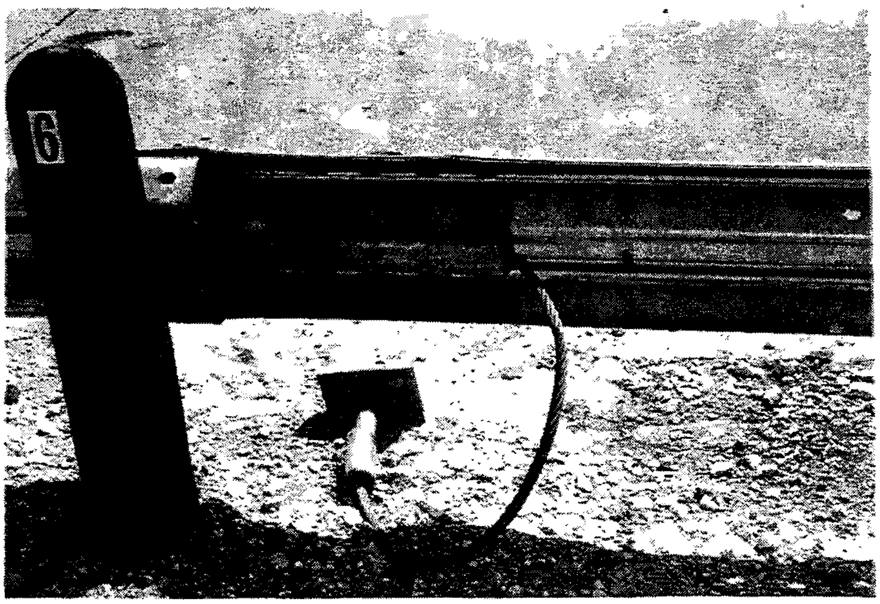


FIGURE F-94. Short Radius Guardrail after Test 1263-6

FIGURE F-95. Damage at posts 8 and 9, Test 1263-6



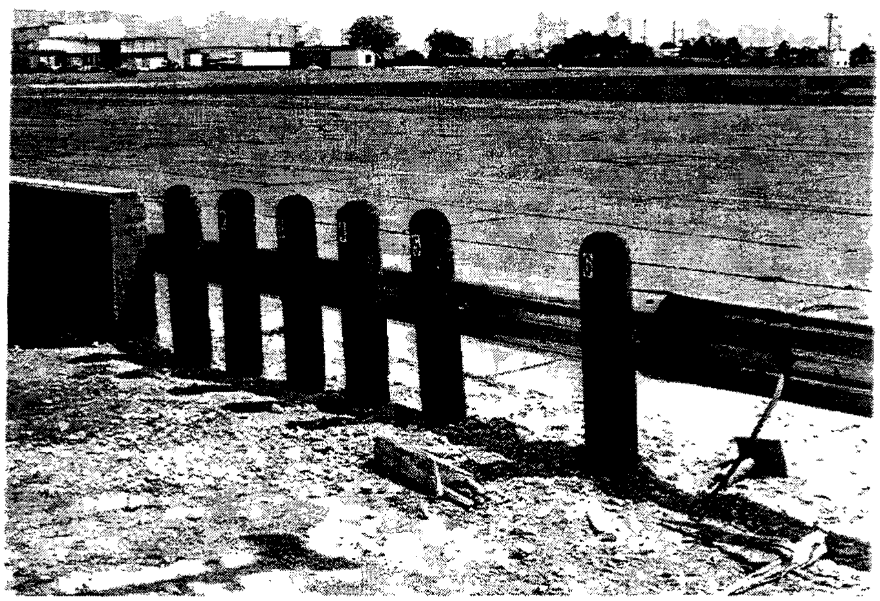


FIGURE F-96. Damage at Post 6, Test 1263-6

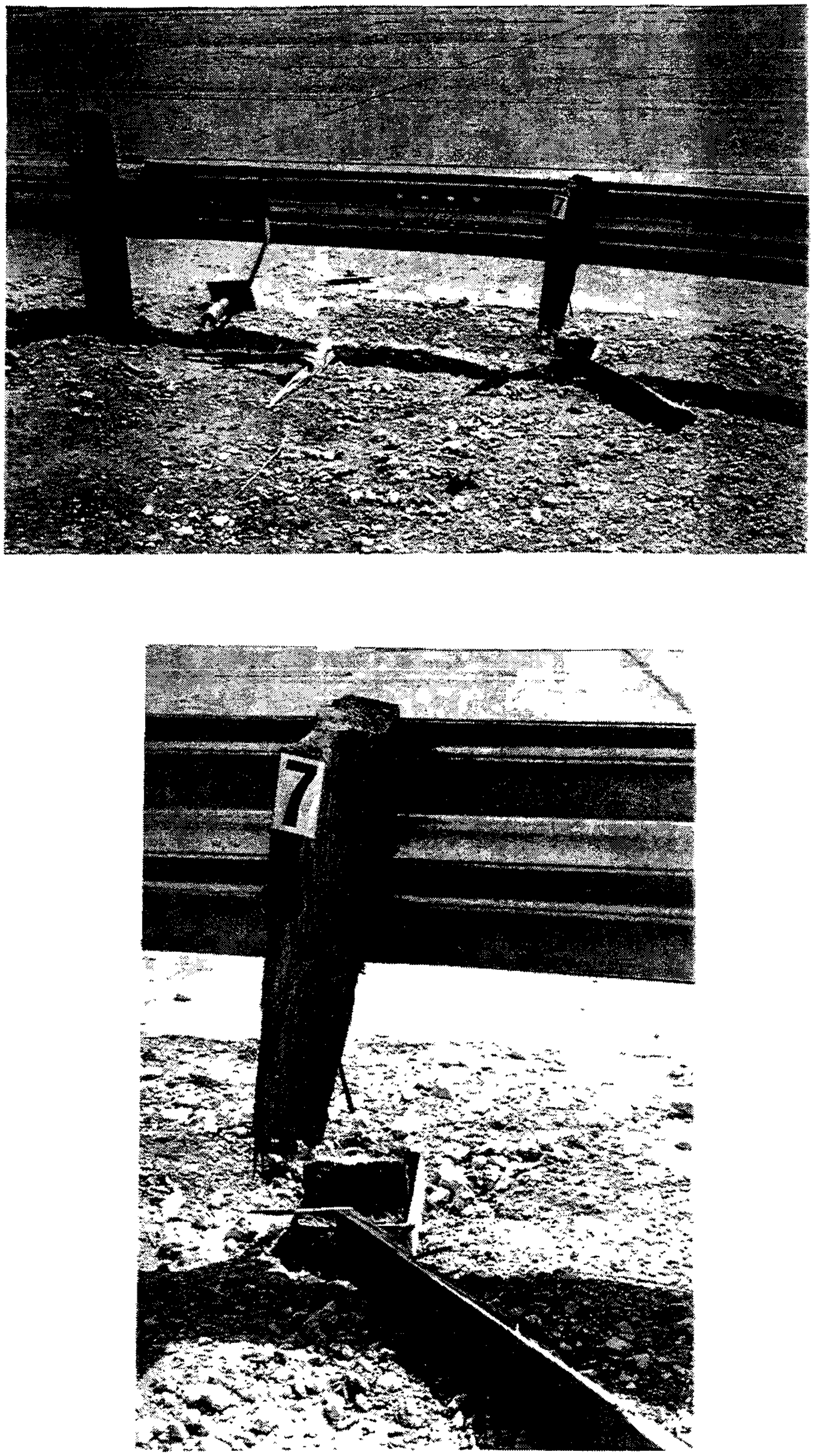


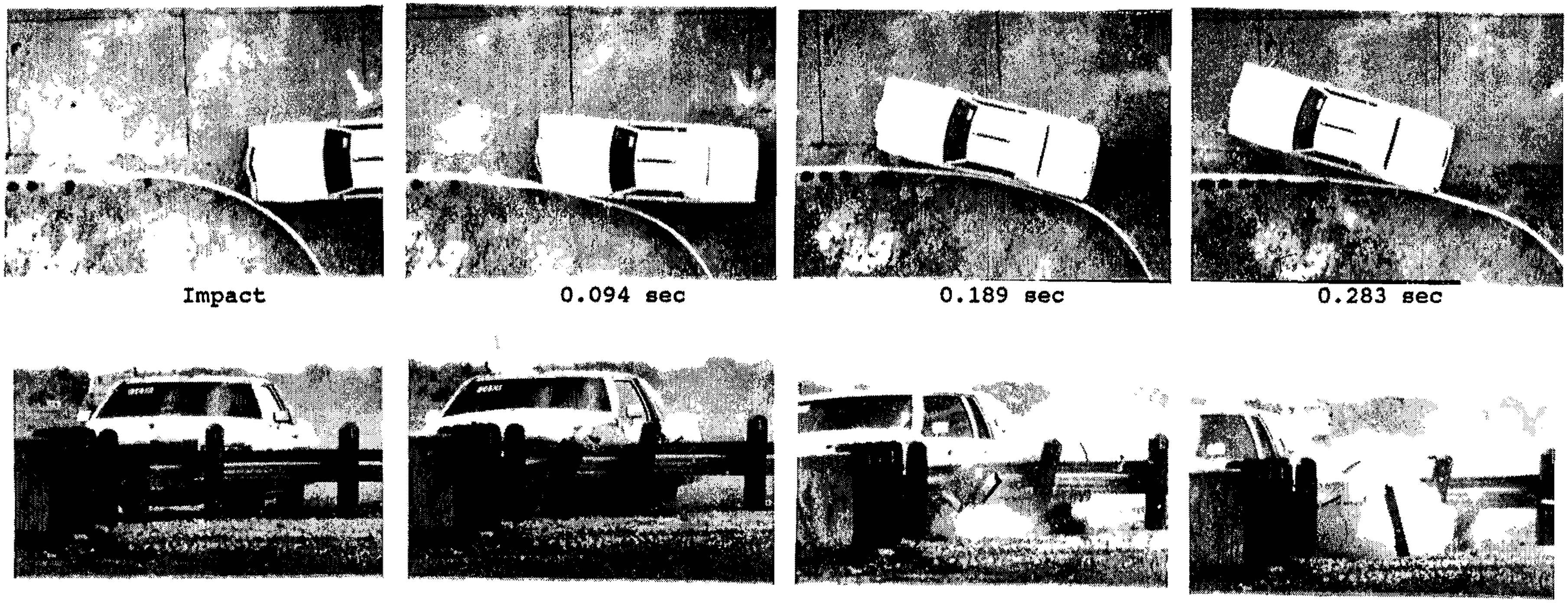
FIGURE F-97. Damage at Post 7, Test 1263-6

As shown in Figure F-98, damage sustained by the vehicle was minor in nature. Maximum crush occurred on the left front corner and was measured to be 9 in. (22.9 cm) rearward and 5 in. (12.7 cm) inboard at bumper height. The crushing to the left side was 2 in. (5.1 cm) just rearward of the left front wheel, increasing to 3.5 in. (8.9 cm) at the left rear corner. The left front tire aired upon contact with a guardrail post. In addition, there was damage to the left front rim, left rear rim, left door, hood, and grill.

Data from the accelerometer located at the center of gravity were digitized for evaluation and occupant risk factors were computed and are reported for information purposes. In the longitudinal direction, occupant impact velocity was 10.7 ft/sec (3.3 m/sec) at 0.294 sec, the highest 0.010-second average ridedown acceleration was -1.6 g between 0.335 and 0.345 sec, and the maximum 0.050-second average acceleration was -2.4 g between 0.009 and 0.059 sec. In the lateral direction, occupant impact velocity 15.4 ft/sec (4.7 m/sec) at 0.142 sec, the highest 0.010-second occupant ridedown acceleration was -5.6 g between 0.220 and 0.230 sec, and the maximum 0.050-sec average acceleration was -4.8 g between 0.038 and 0.088 sec. This data and other pertinent information from the test are summarized in Figure F-99. Sequential photographs of the impact are shown in Figures F-100 and F-101. Vehicular angular displacements are displayed in Figure F-102, and vehicular accelerations versus time traces, filtered at SAE J211 (Class 180), are presented in Figures F-103 through F-105.

This test was judged to be a success. The installation successfully contained and redirected the test vehicle. Although not a requirement for evaluation of a structural adequacy test, the occupant risk criteria were all well below the recommended values established in NCHRP Report 230, further indicating that the vehicle was smoothly redirected without experiencing any severe decelerations. The vehicle remained stable and upright both during impact and after exiting from the installation. Damage to the barrier and vehicle was minor for a test of this severity, and there was not intrusion or deformation of the occupant compartment. The exit velocity of the vehicle was well below the recommended limit set forth in NCHRP Report 230.

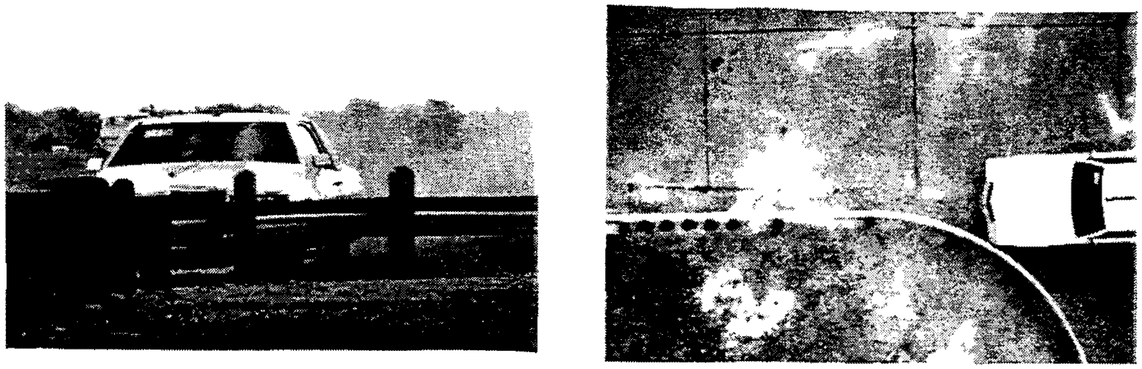
FIGURE F-98. Vehicle after Test 1263-6



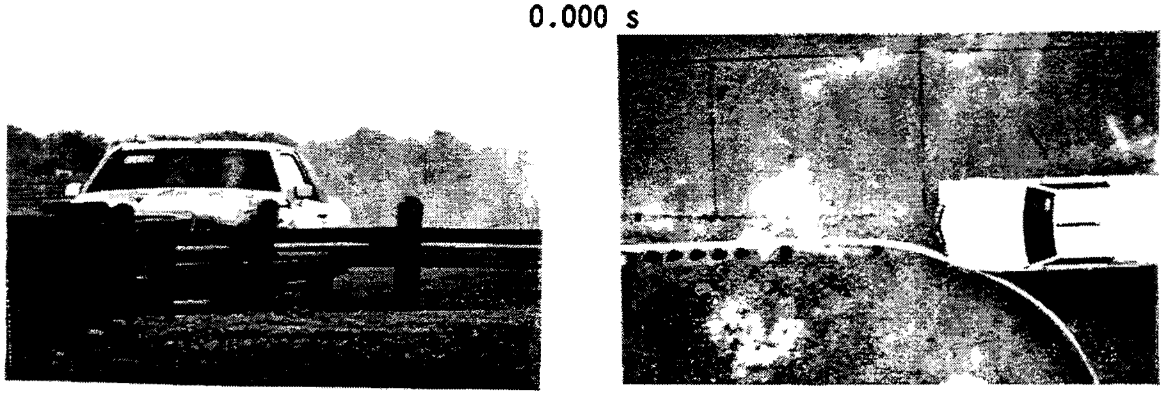

```
Test No. . . . . . . . . . 1263-6
Date . . . . . . . . . . . 08/31/92
Test Installation  . . . Short-Radius
                         Guardrail Treatment
Installation Length  . . 100 ft (30 m)
Max. Dynamic Movement  . Not Obtained
Max. Perm. Movement  . . 2 in (5.1 cm)
Test Vehicle . . . . . . 1983 Cadillac Coupe
Vehicle Weight
  Test Inertia . . . . . 4,500 lb (2,041 kg)
  Gross Static . . . . . 4,500 lb (2,041 kg)
Vehicle Damage Classification
  TAD  . . . . . . . . . 10LD2
  CDC  . . . . . . . . . 10LFEW2
Maximum Vehicle Crush. . 9.0 in (22.9 cm)
```

```
Impact Speed. . . . . 58.3 mi/h (93.8 km/h)
Impact Angle. . . . . 2.0 deg
Speed at Parallel . . 53.7 mi/h (86.4 km/h)
Exit Speed  . . . . . 52.8 mi/h (84.9 km/h)
Exit Trajectory . . . 16.6 deg
Vehicle Accelerations at center-of-gravity
  (Max. 0.050-sec Average)
  Longitudinal. . . . -2.4 g
  Lateral . . . . . . -4.8 g
  Occupant Impact Velocity at true c.g.
  Longitudinal. . . . 10.7 ft/s (3.3 m/s)
  Lateral . . . . . . 15.4 ft/s (4.7 m/s)
Occupant Ridedown Accelerations
  Longitudinal  . . . -1.6 g
  Lateral . . . . . . -5.6 g
```

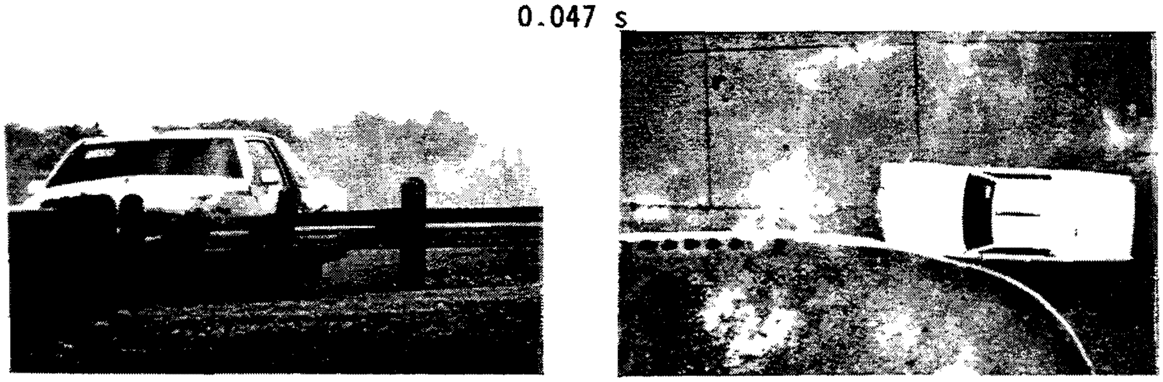
FIGURE F-99. Summary of Results for Test 1263-6



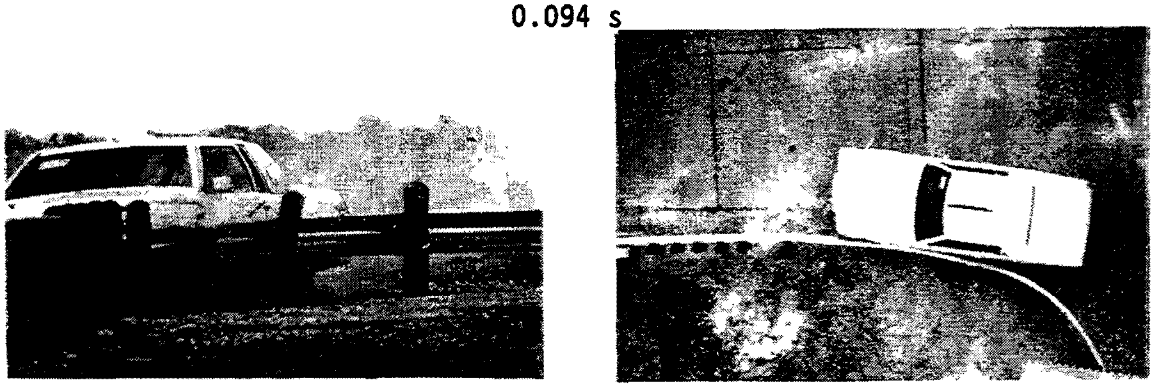
0.000 s



0.047 s

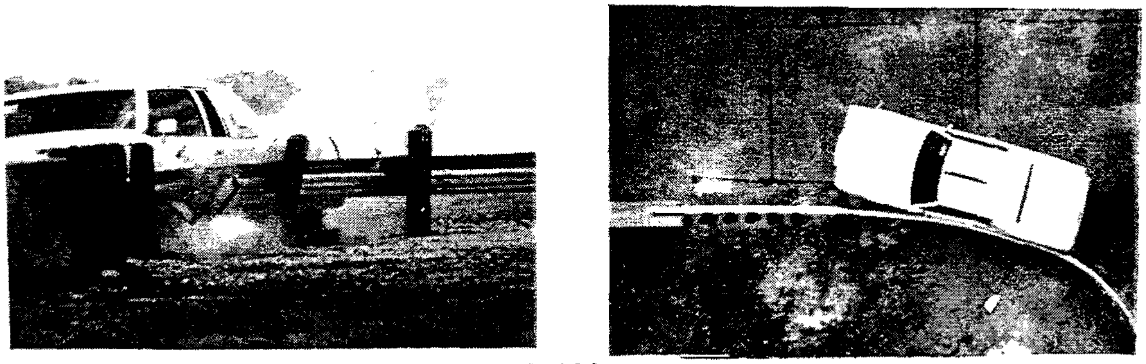


0.094 s

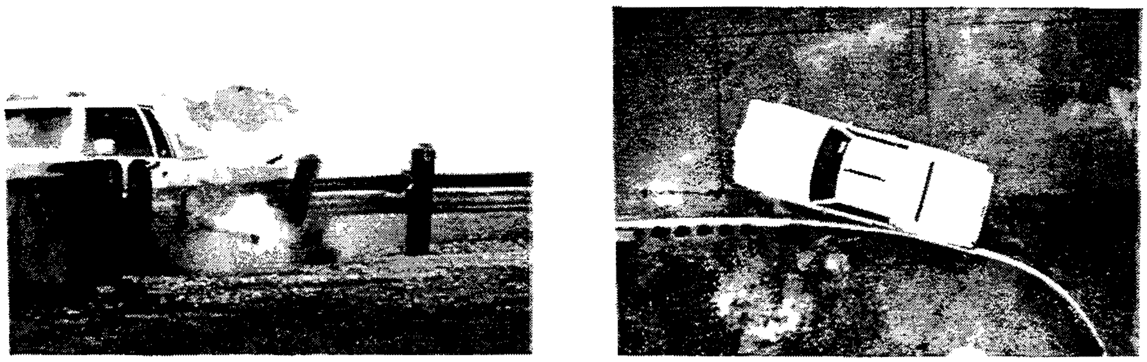


0.142 s

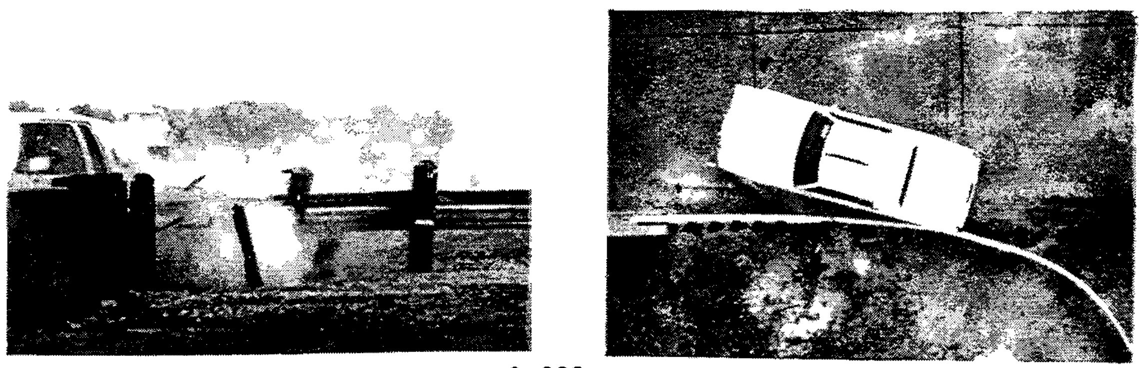
FIGURE F-100. Sequential Photographs for Test 1263-6 (Frontal and Overhead)



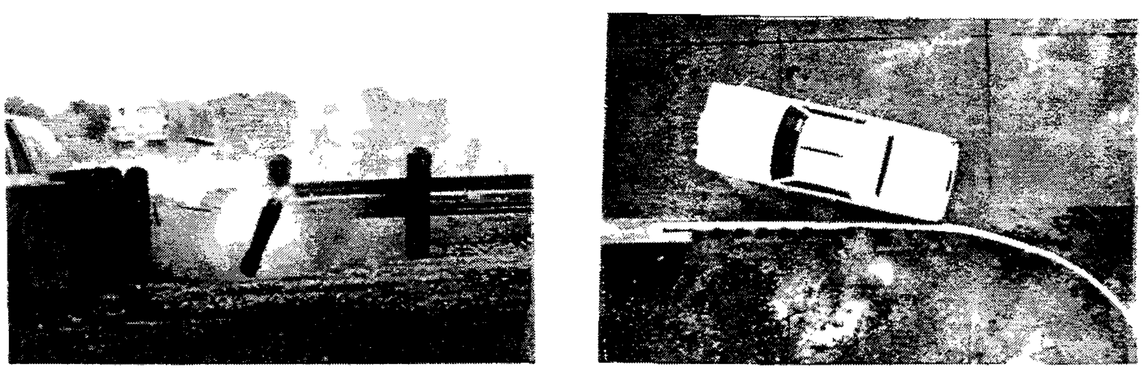
0.189 s



0.236 s



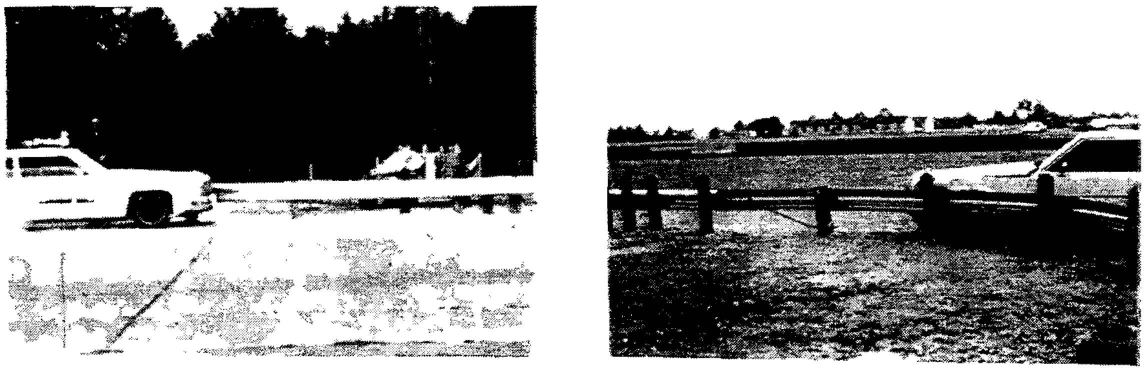
0.283 s



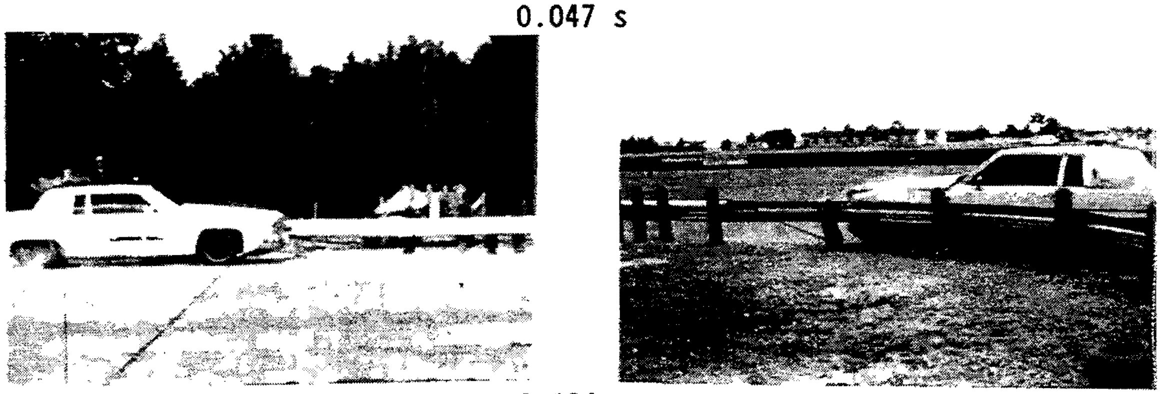
0.330 s

FIGURE F-100. Sequential Photographs for Test 1263-6 (Frontal and Overhead) (continued)

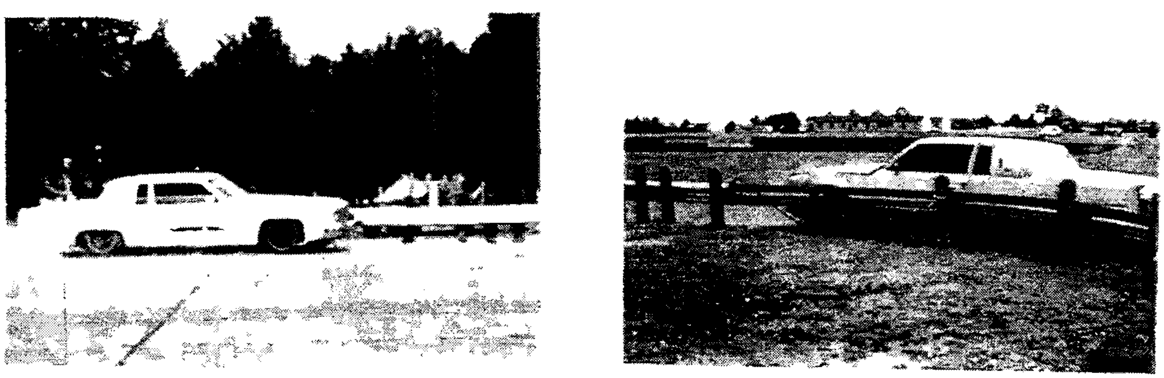
0.000 s



0.047 s

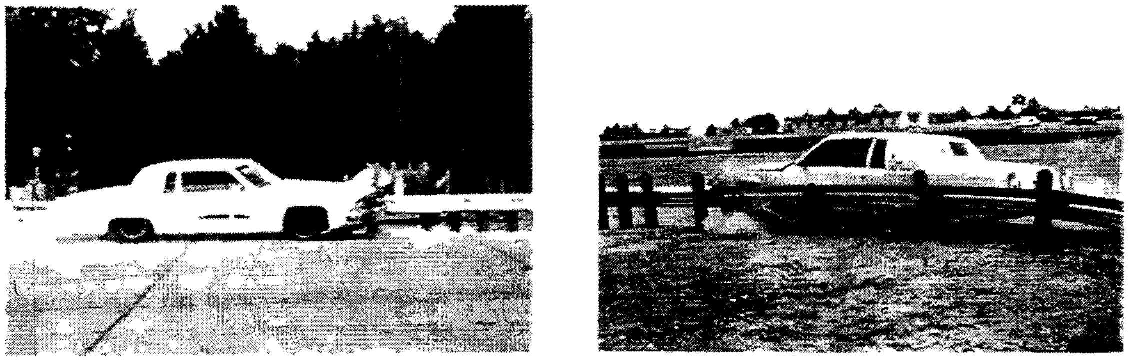


0.094 s



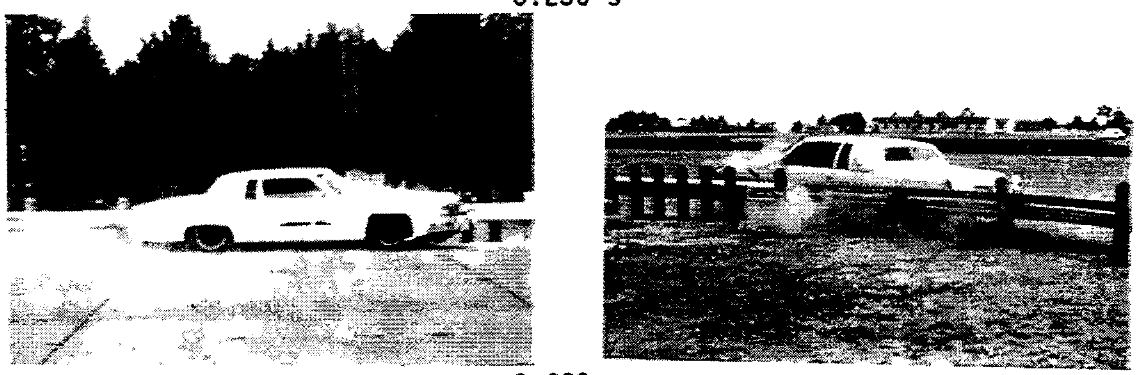
0.142 s

FIGURE F-101. Sequential Photographs for Test 1263-6 (Side Views)

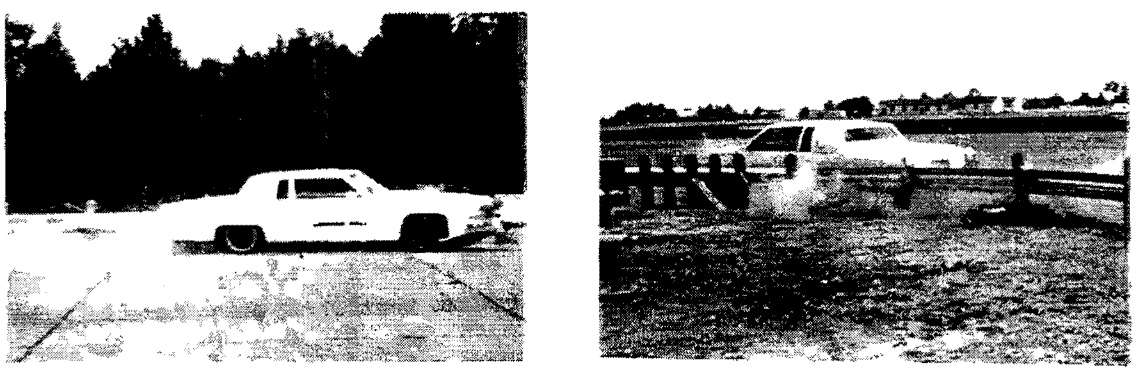


0.189 s

0.236 s



0.283 s



0.330 s

FIGURE F-101. Sequential Photographs for Test 1263-6 (Side Views) (continued)

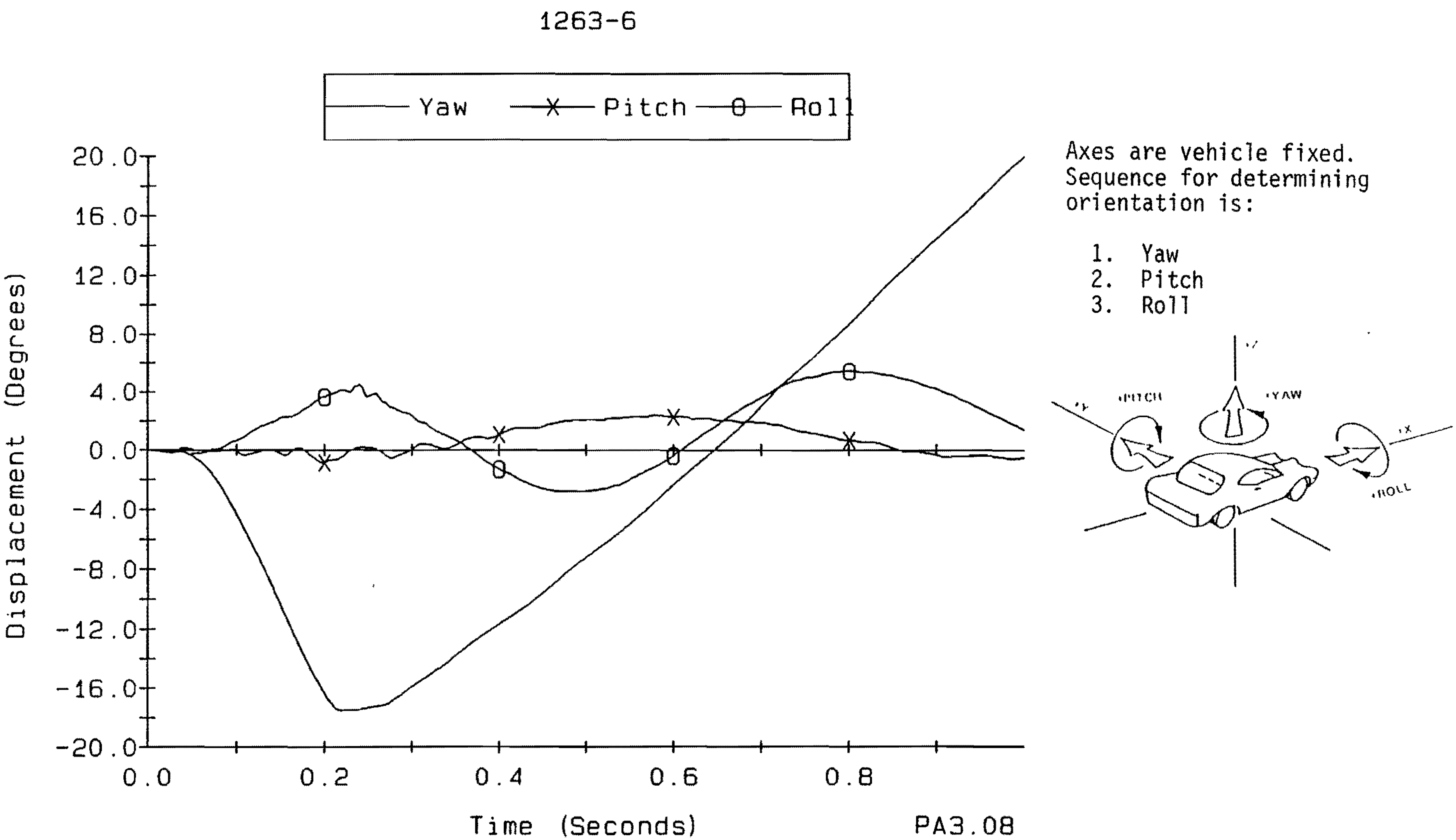


FIGURE F-102. Vehicle Angular Displacements for Test 1263-6

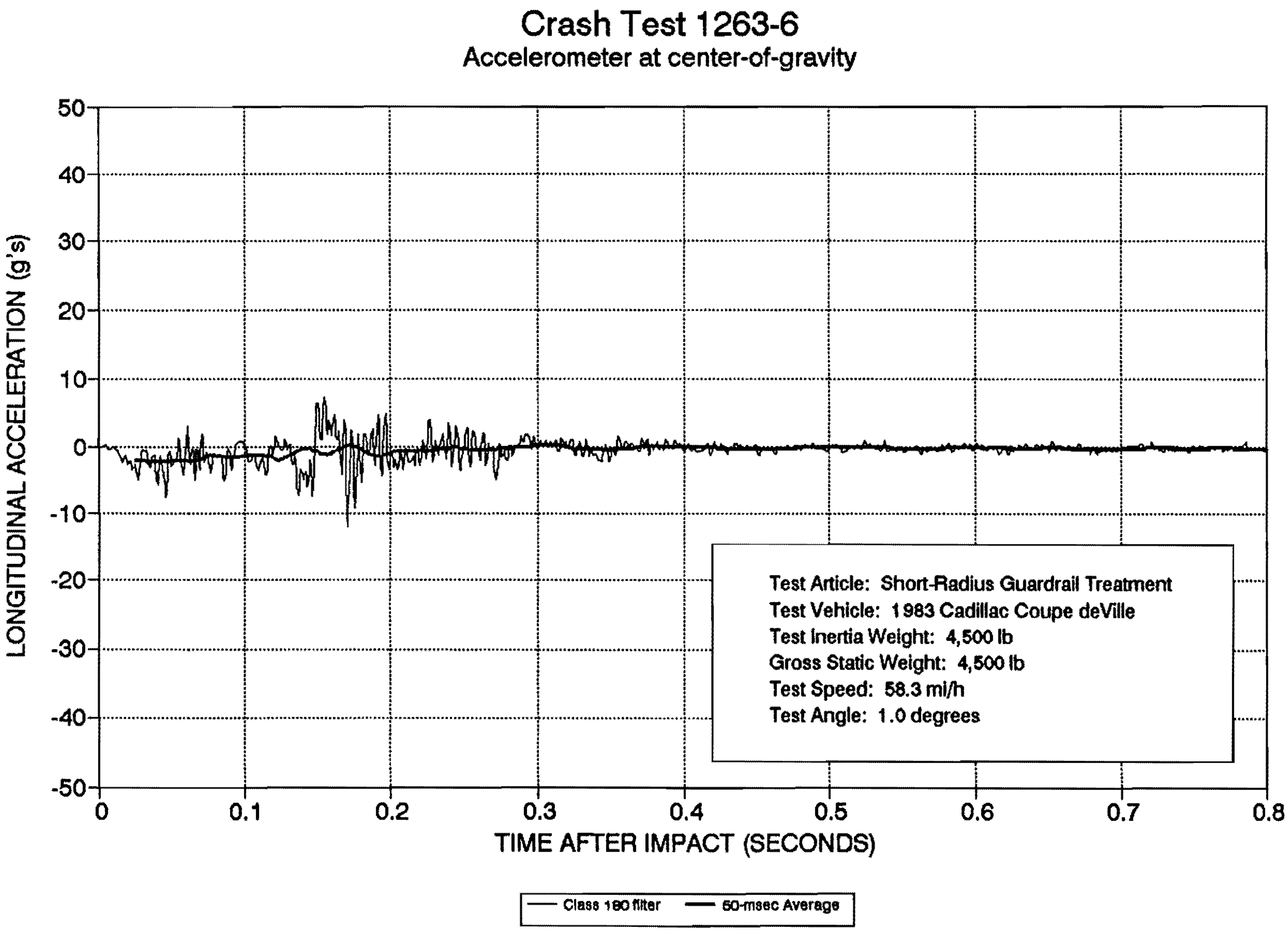


FIGURE F-103. Longitudinal Acceleration Trace for Test 1263-6

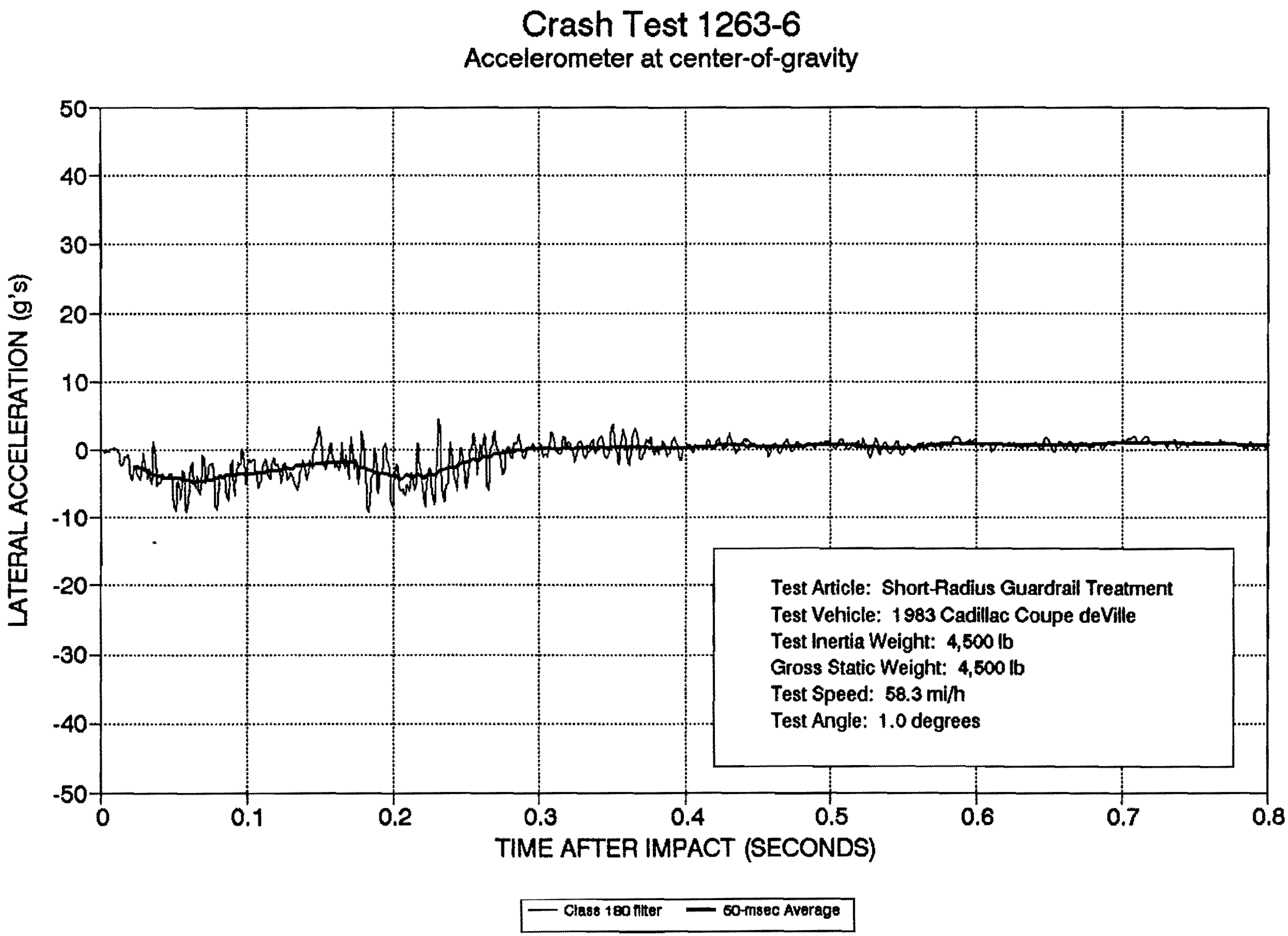


FIGURE F-104. Lateral Acceleration Trace for Test 1263-6

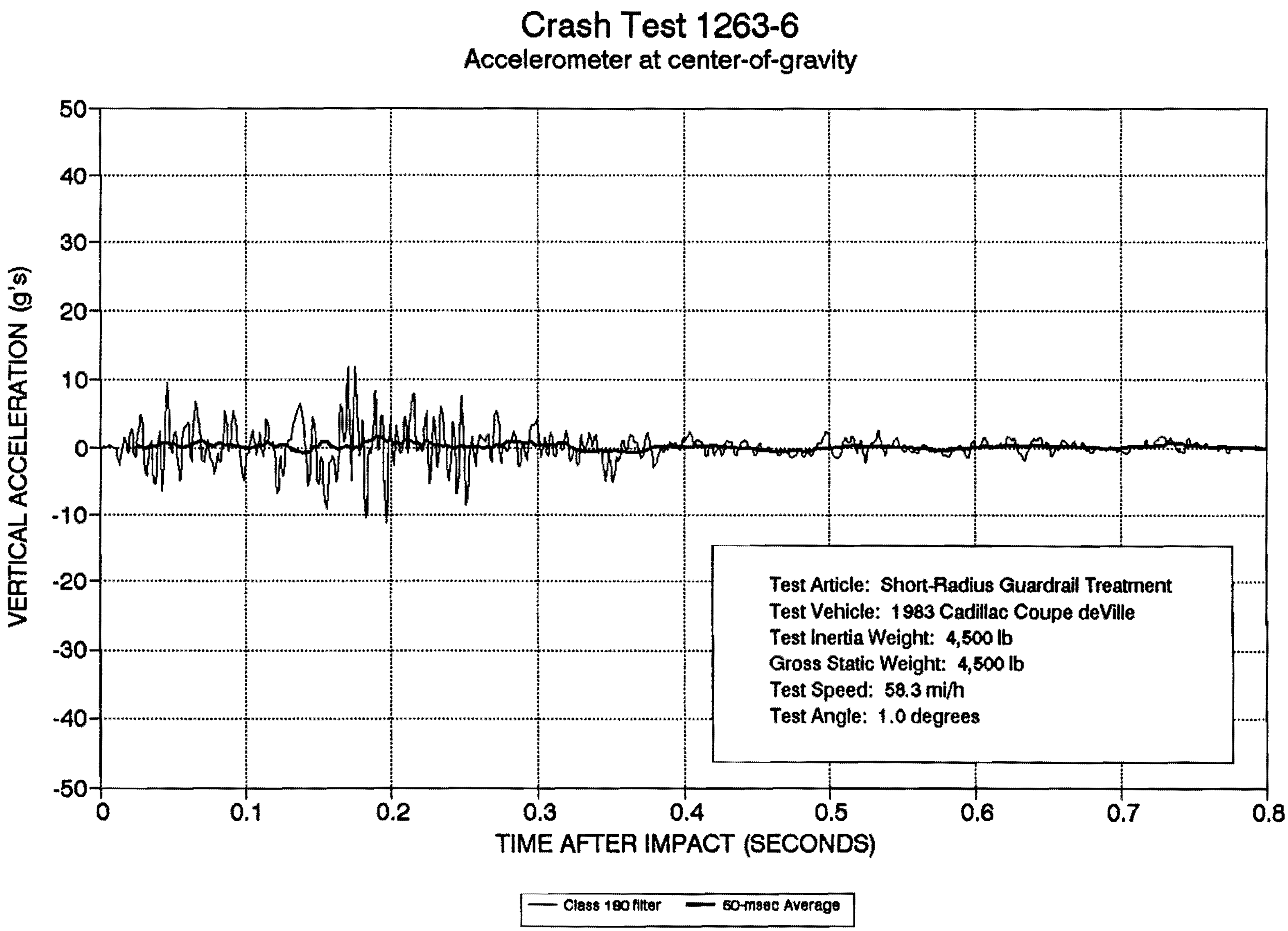


FIGURE F-105. Vertical Acceleration Trace for Test 1263-6