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An Analysis of Guardrail and Median Barrier Accidents Using the Longitudinal Barrier Special Studies (LBSS) File

Volume I: Final Report

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

This report documents a study that examined the effectiveness of guardrails and median barriers on the Nation's highways using the Longitudinal Barrier Special Studies (LBSS) crash file. The research included accident reconstruction, and clinical and statistical analysis to investigate such issues as the severity of injury associated with specific barrier types. The data were compared to State accident data to investigate potential bias in terms of crash severity.

This report will be of interest to researchers and agencies involved in roadside safety research as well as practicing engineers with responsibility for managing roadside safety.

Lyle Saxton

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Director, Office of Safety and Traffic
Operations Research and Development

NOTICE

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Abstract: In the study, the Longitudinal Barrier Special Studies (LBSS) file was cleaned for use in examining the real-world performance of longitudinal barriers. Given that impact speeds were mostly missing from the LBSS file, impact speeds were reconstructed for several accidents. An examination of the accuracy of reconstructed impact speeds was also performed using input from three experts in barrier accident reconstruction. Descriptive and statistical analyses were performed to compare one barrier type vs. another in terms of driver injury. Where appropriate, logistical models were developed that utilized impact speed, impact angle, and vehicle curb weight as covariates. Another comparison involved severity of impacts to ends vs. length of need (LON). Nearly 1,200 cases were available for analysis. Two-thirds of the cases involved a LON and one-third involved an end impact. Two-thirds of the cases involved guardrail accidents; the remainder were median barrier accidents. Clinical analysis of barrier performance was also undertaken to learn more about length-of-need segment failures and barrier-ends. The volume is the first in a series. The other volume in the series is FHWA-RD-92-099 Volume II: Users Guide (PB95-137808).

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16. Abstract

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Clinical analysis of barrier performance was also undertaken to learn more about length-of-need segment "failures" and barrier-ends.

This volume is the first in a series. The other volume in the series is FHWA-RD-92-099 Volume II: Users Guide.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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

(Revised September 1993)

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I. INTRODUCTION

BACKGROUND

The Longitudinal Barrier Special Study (LBSS) file was developed within the National Accident Sampling System (NASS). The NASS Continuous Sampling System (CSS) was a continuous nationwide accident data collection program sponsored by the U.S. Department of Transportation (USDOT) from 1979 through 1986. Data was collected by NASS investigators working through various zone centers in the U.S.[1]

While NASS was developed to provide an automated, comprehensive national traffic accident data base, LBSS was developed by the Federal Highway Administration (FHWA) to address collisions involving longitudinal barriers (both guardrail and median barriers).

Accidents within NASS CSS are a probability sample of all police-reported accidents occurring in the U.S. from year to year. These accidents are then weighted to represent all police-reported accidents in those years.

Accidents meeting a series of eligibility criteria were selected for possible inclusion in LBSS.

To be eligible, an accident had to:

- Be reported by the police in a primary sampling unit area of the NASS.
- Involve a vehicle (other than a motorcycle) striking a guardrail or median barrier.

The accidents were stratified by:

- Most severe injury level reported (fatal, incapacitating, non-incapacitating, no injury).
- Disposition of accident victims (whether or not victims were transported to a medical facility).
- Type of vehicle involved (light truck or van, medium or heavy truck, etc.).
- Disposition of the case vehicle (whether or not towing was required).

The following data had to be available: (1) barrier damage, (2) trajectory, and (3) vehicle damage.

Data was collected from 1982 to 1986. From mid-1983 on, accidents involving vehicle-to-vehicle impacts prior to guardrail or median barrier impact were not eligible. A total of 1,146 accidents met all acceptance criteria and were included in the study.

SCOPE

The objectives of this study were to:

- Review and cleanse the LBSS file. This involved recoding some variable data for consistency and correcting erroneous data. A major effort involved reconstructing the accident impact speeds.

- Statistically analyze the accident data, specifically to examine the severity of barrier "length of need" (LON) vs. barrier-end impacts.[1]

- Clinically analyze the various barrier failures by barrier system type (e.g., G1, G2, G4, etc.).

GENERAL

Critical to any analysis using the LBSS file was a clean data base. It was essential to have data consistently coded from year to year and to verify the accuracy of key data elements. A comprehensive review of all the subsets (files containing data pertaining to accident, barrier, driver, occupant, and vehicle variables) of the LBSS file was performed. The review utilized hard copies of each subset, including slides and photographs, to check coded values.

Given that impact speeds were mostly missing from the LBSS file, an effort was made to reconstruct the impact speeds for as many accidents as possible. Principles of energy conservation were used in conjunction with data obtained from the file (vehicle weight and impact angles). For the more complex accidents, speed estimates were provided by an investigator with extensive crash-testing experience.

Details of the file cleanup and reconstruction of speeds are presented in chapter II.

The effort to clean up the LBSS file provided a file usable for data analyses purposes. These analyses, briefly described below, were both statistical and clinical in nature and match the aforementioned study objectives.

The primary focuses of the statistical analysis were to study the injury severity by barrier type and severity of injuries sustained in impacts into barrier LON segments against those sustained in impacts into barrier-ends. The accidents in the LBSS file primarily involved impacts within the typical flexible or semi-rigid barrier length (same as length of need) and impacts with the barrier-end (both upstream and downstream). Table 1 shows the sample sizes for each of the barrier segments in the file. As part of the statistical analysis, data in the LBSS file were compared to data in accident files from five States in an attempt to determine

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[1] Signifies impact within the typical flexible or semi-rigid barrier length.

how representative the file was of barrier accidents within the Nation. A report on that determination is included in chapter III.

Table 1. Sample sizes for each of the barrier segments.

Barrier Segment	Sample Size
Length of Need	
Guardrail	571
Median Barrier	427
Barrier End	
Upstream	
Guardrail	328
Median Barrier	26
Downstream	
Guardrail	94
Median Barrier	9
Total	1456

As part of the analysis, the safety performance of the various types of guardrails and median barriers and types of end treatments was studied. This included a comparison of risk to the driver when striking a barrier LON section vs. a barrier-end section. Both topics have always been of interest for roadway and roadside design and safety engineers as well as others interested in the performance of roadside hardware.

An analysis of barrier performance (barrier failures for LON cases) was also undertaken. This analysis was clinical in nature due to the small sample counts encountered when barrier failures were categorized by barrier system type. The clinical analysis was performed in two stages:

The LON accidents, where the accident vehicle was not redirected, were individually studied to determine why the barrier did not perform according to its intended purpose.

The consideration of performance for barrier-ends (or terminals) is more complex. A terminal may perform as designed, but still cause injuries or fatalities [e.g., vehicle riding on top of a "turndown" and striking a fixed object, or a side impact into a breakaway cable terminal (BCT)]. All impacts involving barrier-ends were reviewed and their performances were categorized.

Reports on the safety and barrier performance analyses are presented in chapters III and IV, respectively.

II. LBSS FILE CLEANUP AND IMPACT SPEED RECONSTRUCTION

FILE CLEANUP

Some Continuous Sampling System (CSS) data element definitions were revised in each of the data collection years and several Longitudinal Barrier Special Study (LBSS) data elements were revised to meet changing analytical requirements.[1] In order to adequately perform any analysis on the LBSS file for all the years involved, all such data elements had to be recoded to ensure consistency across years. All affected variables were determined and recoded. A comprehensive list of variables recoded in each LBSS file is provided in the LBSS user's guide.[2]

The cleanup process included a review of the set of accident forms for each accident case. The review included a check of key data elements such as impact angle, barrier type impacted, barrier rail type, and block-out presence. During the review process, several of the data elements in the files were found to have been coded in error. These included barrier systems (e.g., G2, G4, etc.) being incorrectly identified and impact angles being incorrectly coded. These errors were corrected.

IMPACT SPEED RECONSTRUCTION

The individual accident cases in the LBSS file have extensive documentation when compared to other sources of accident data (e.g., police reports). Although a number of measurements of the accident scene and the vehicle are recorded both numerically and photographically, each accident represents a unique and complex series of events.

Several reconstruction procedures were reviewed to determine the method(s) most appropriate for this work. Features taken into consideration included the time and effort required to develop or modify the procedure, any previous use of the procedure, and any evaluations of previous efforts.

The procedures reviewed included: (1) the method used in the FHWA study entitled, "Rollover Caused by Concrete Safety Shaped Barriers"; (2) the method used in the study entitled, "Multiple-Service-Level Highway Bridge Railing Selection Procedures" reported in the NCHRP Report 239; and (3) the method developed as a part of the National Highway Transportation Safety Administration study entitled, "Longitudinal Barrier and Crash Cushion Accident Reconstruction Procedures."[3,4,5]

The procedure developed under (3) above was validated only for G4 guardrail and the authors indicated that further work would be required to develop energy relationships for barriers other than the G4. Such an effort was outside the resources of this contract. The method used under (2) above was developed to predict occupant injury given impact conditions and no further review of this method was pursued. The method developed under

(1) above was adopted for concrete safety shaped barriers. It assumes that the barrier, in rigid-barrier accidents, does not deflect and the energy dissipation does not include the corresponding terms.

For impacts within the typical flexible or semi-rigid barrier length (LON section) where there are no end effects or significant changes in barrier/terrain geometry, relationships established from crash test findings were used to determine the speed of the vehicle. For the more difficult transition (i.e., different barrier configuration within the impact zone) and end treatment accidents, considerably more judgment and estimations were required to determine vehicle speed.

Scope

The speed reconstruction aspect of this project was performed to provide impact speeds for use in data analyses. As previously mentioned, impact speeds were mostly missing from the LBSS file. Since project emphasis was on analyses, limited resources were allocated for reconstructing impact speeds. Accordingly, some simplified expressions were used to estimate speeds and these speeds are considered to be precise only to within ± 10 mi/h (16.1 km/h).

The accidents contained in the LBSS files typically occurred at the following longitudinal barrier locations:

- Within the LON.
- At the transition zone between different barrier systems.
- At or near the end of the terminal.

Impact speeds in the accident cases involving transitions were reconstructed using the same procedures as the LON cases, but adjusted according to the specifics of each accident.

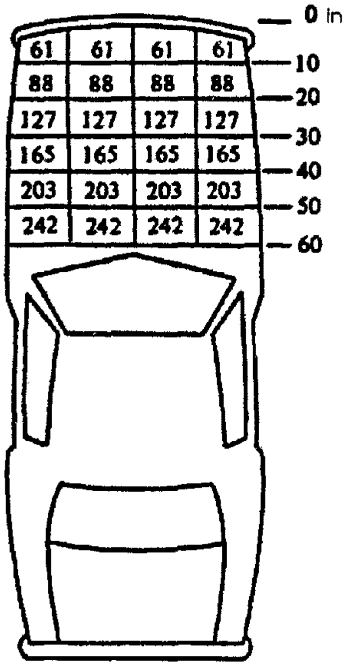
Barrier LON Speed Reconstruction

The basic principle used for reconstructing speeds is conservation of energy. The total energy (TE) absorbed in an accident comes from the following three components:

TE = Energy (vehicle crush) + Energy (barrier deformation) + Energy (vehicle trajectory)

Calculation of each of these components are described in the following three subsections.

Vehicle Crush. The energy absorbed in vehicle crush comes from the visual method and equations presented in reference 6. Figure 1 shows the method that involves dividing the vehicle front end into sections and determining the energy absorbed by each section. The width of the vehicle front end is divided into four equal sections and the length (representing increments in vehicle crush) is divided into 10-in (254-mm) increments. The



1 in = 25.4 mm

Figure 1. Vehicle crush vs. energy.

extent of crush was determined visually by inspecting pictures of crash vehicles. The numbers shown on the vehicle front end in figure 1 represent the energy absorbed by each section in units of velocity squared. The numbers in the body of table 2 are the values for a small and large vehicle. These numbers can then be used with the equations provided in the table to calculate the vehicle crush component of the impact speed (V_c). This component is used in determining the total energy absorbed.

Barrier Deformation. The energy absorbed in barrier deformation is obtained from the curves of crash severity index vs. maximum dynamic deflection (number of failed posts is used for cable barrier systems) developed for the flexible longitudinal barriers. A sample curve is shown in figure 2. The severity index is the same as that used in the National Cooperative Highway Research Program Report 230 and is equal to $\frac{1}{2}$ m (v sin θ)^2 where m is vehicle inertial mass in slugs (kg); v is impact speed in ft/s (m/s); and θ is impact angle in degrees.[10]

Using the energy value obtained from the severity curves and the severity index equation, the deformation component of the impact speed (V_d) can be calculated. The curves were based on a series of computer simulations performed using BARRIER VII as part of work reported in FHWA-RD-78-74 entitled "Development of a Cost-Effectiveness Model for Guardrail Selection."[7]

Table 2. Energy absorbed by vehicle crush.

$V_c = 3.0 + 1.35(\text{Energy})$ 2250-lb ‘71-‘74Vega

1.00	2.00	3.00	4.00	
				0.0 in
2.27	2.27	2.27	2.27	10.0
5.24	5.24	5.24	5.24	20.0
8.29	8.29	8.29	8.29	30.0
11.33	11.33	11.33	11.33	40.0
14.37	14.37	14.37	14.37	50.0
17.42	17.42	17.42	17.42	60.0

$V_c = 6.85 + 0.88(\text{Energy})$ 4500-lb ‘71-‘72GM

1.00	2.00	3.00	4.00	
				0.0 in
2.05	2.05	2.05	2.05	10.0
2.95	2.95	2.95	2.95	20.0
4.24	4.24	4.24	4.24	30.0
5.53	5.53	5.53	5.53	40.0
6.83	6.83	6.83	6.83	50.0
8.12	8.12	8.12	8.12	60.0

1 lb = 0.454 kg, 1 in = 25.4 mm

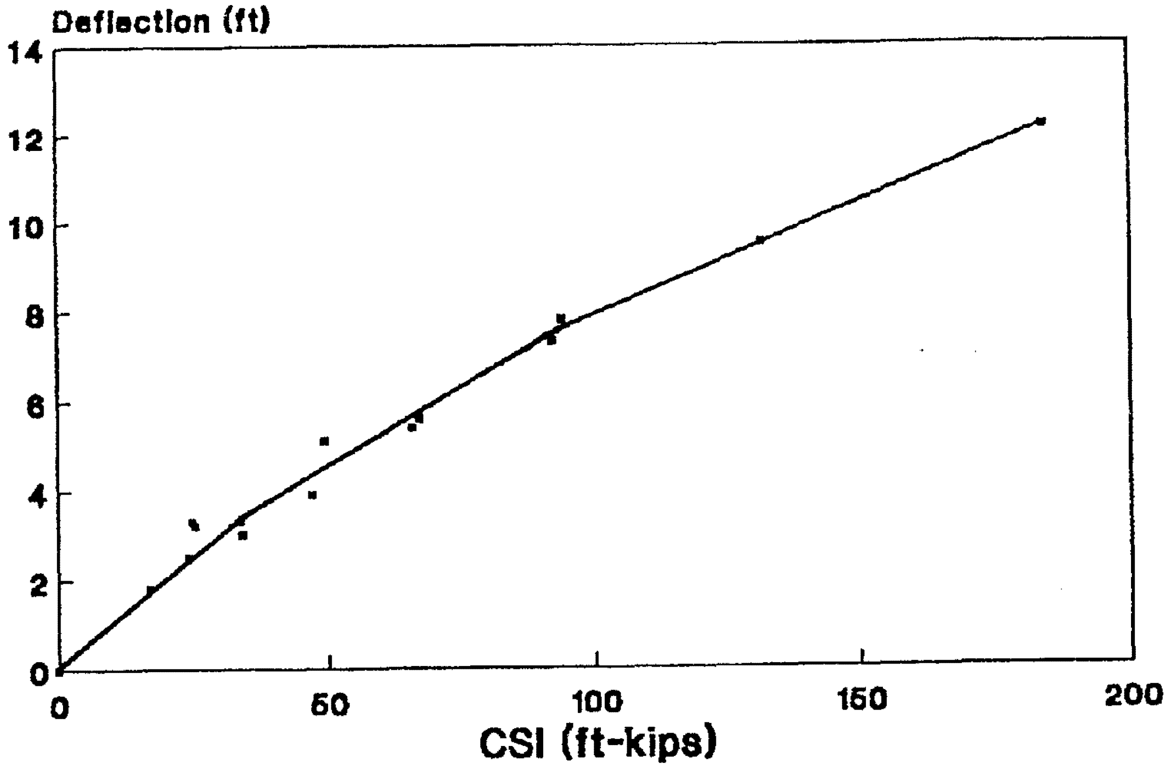
Energy: Represents energy absorbed by each front end section.

Because the simulations predicted dynamic deflection and the accident cases reported permanent deflection, an adjustment was made to the curves. This adjustment was determined by dividing the dynamic deflections by the permanent deflections from several full-scale crash tests on standard guardrails and is defined as follows:

Dynamic deflection = (k) * (permanent deflection)

where:

k = 1.5 for permanent def $\geq$ 12 in (30 mm)
4.0 for permanent def < 12 in (30 mm)



1 ft = 0.305 m, 1 ft-kip = 1356 N•m

Figure 2. Plot of G2 crash severity index (CSI) vs. deflection.

Vehicle Trajectory. The energy absorbed in the vehicle trajectory is based on equations of motion:

$$V_t = \sqrt{V_1^2 + 2aS} \qquad (1)$$

where:

V_t = trajectory component of impact speed
V_1 = final velocity (= 0 for car at rest)
a = acceleration
S = distance traveled

For skidding and sliding, this equation is modified to include the friction factor. For rotating vehicles, the distance is based on the angle of rotation and the radius. The energy absorbed by the vehicle trajectory may then be calculated by multiplying V_t by one-half times the vehicle mass.

After obtaining all three components of energy absorbed, the total impact speed may then be determined using:

$$V = (V_c + V_d + V_t) \tag{2}$$

For accidents where the vehicle impacted the barrier with little or no yawing and was readily redirected, the severity equation was used to determine the impact speed (equation 3). The crash severity index (CSI) was obtained from the severity curves (figure 2).

$$V = \frac{\sqrt{\dfrac{2*32.2*CSI}{weight}}}{\sin(impact\triangle)} \tag{3}$$

where:

V = impact speed

This simplified reconstruction procedure was limited to accidents involving tracking vehicles impacting flexible barrier length-of-need sections. A sample reconstruction worksheet is shown in figure 3. For the other more complex LON accidents, equation 1 was modified and adjusted according to the specifics of each accident.

Barrier End Speed Reconstruction

The predominant end treatments in the LBSS file are:

- W-beam turndown.
- W-beam blunt end.
- Breakaway cable terminal (BCT).

The estimated speed from these cases was determined by using simplified analysis and estimates based on the experience of an investigator who has witnessed over 600 crash tests and reviewed reports on at least that many more. These end treatment accidents are in many cases extremely complicated events with limited crash test comparisons available.

Included in the techniques for estimating speed are the following:

- Simplified analysis using an estimated vehicle drag (e.g., friction) and trajectory (see figure 4).

- Velocity change related to vehicle crush combined with trajectory/run-out calculations (see figure 5).

- Vehicle/barrier damage and occupant injuries (see figure 6).

- Crash test experience (see figure 7).

- Yaw marks (see figure 8).

Simplified Analysis. The estimated drag factor can be pavement friction, vehicle/barrier interface friction, or some other estimated drag factor. This factor is applied over the distance where this resistance is recorded and vehicle speed is computed using the expression

$$V = \sqrt{30 \mu D} \tag{4}$$

where:

V = impact speed, mi/h (km/h)
μ = drag or friction value
D = distance over which the drag factor is applicable

Crush Combined with Run-Out. The estimated velocity change due to vehicle crush is added to the velocity determined in the previously explained simplified analysis.

Vehicle/Barrier Damage and Occupant Injuries. This is a subjective estimate based on crash test experience and assumes that a 30 mi/h (48.3 km/h) velocity change will produce severe injuries for unrestrained occupants.

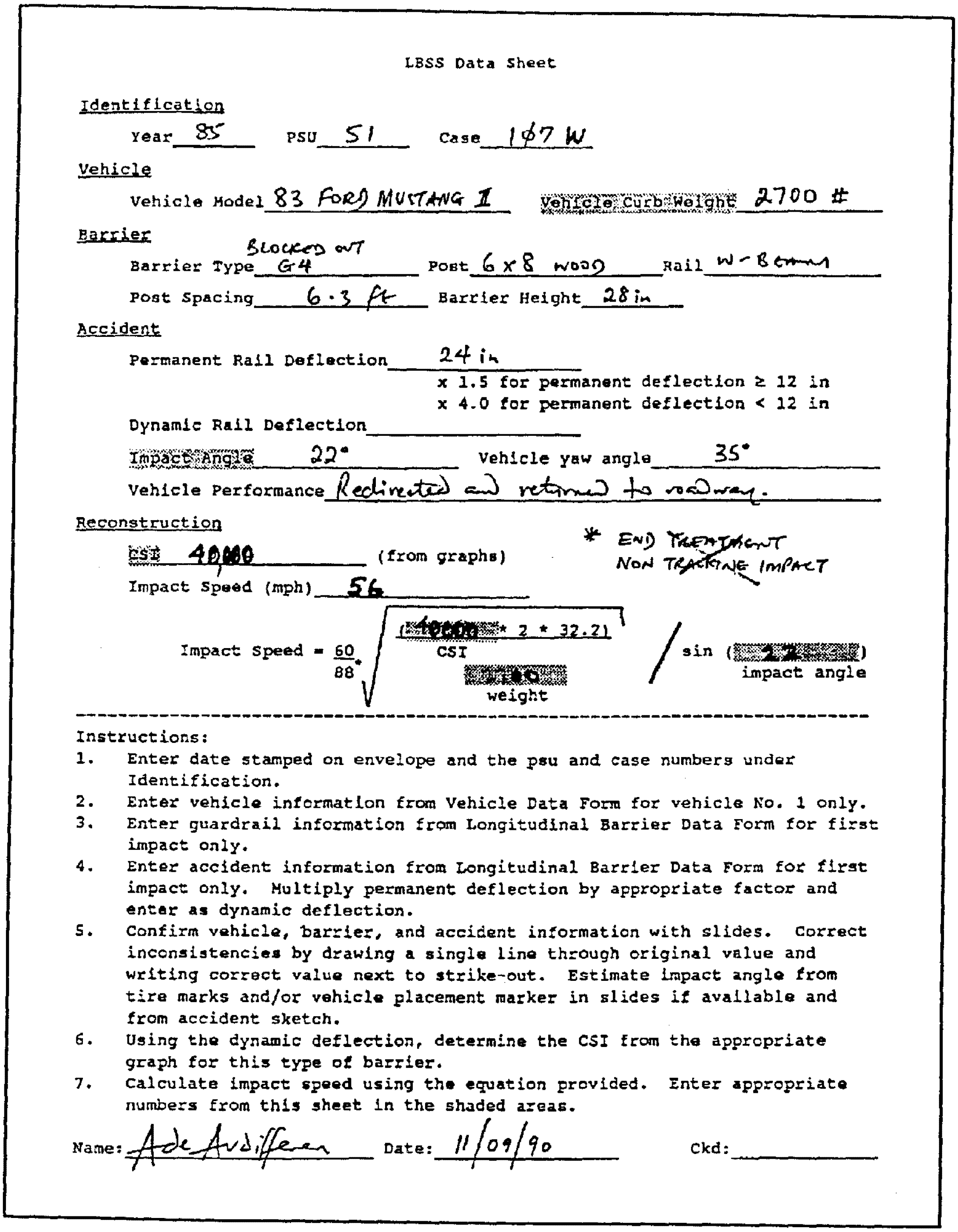
Crash Test Experience. The impact is closely associated with known crash tests and thus can be related to the crash test conditions.

Yaw Marks. In some cases, the tire marks were drawn to scale by the investigator. A radius was computed from these marks and an estimated speed was calculated using the expression:

$$V = \sqrt{15 \mu R} \tag{5}$$

where:

V = estimated impact speed, mi/h (km/h)
μ = estimated sliding friction
R = yaw mark radius.



LBSS Data Sheet

Identification

Year 85 PSU 51 Case 107 W

Vehicle

Vehicle Model 83 FORD MUSTANG II Vehicle Curb Weight 2700 #

Barrier

Barrier Type BLOCKED OUT G4 Post 6 x 8 WOOD Rail W-Beam

Post Spacing 6.3 ft Barrier Height 28 in

Accident

Permanent Rail Deflection 24 in

x 1.5 for permanent deflection ≥ 12 in

x 4.0 for permanent deflection < 12 in

Dynamic Rail Deflection ________

Impact Angle 22° Vehicle yaw angle 35°

Vehicle Performance Redirected and returned to roadway.

Reconstruction

CSI 40,000 (from graphs) * END TREATMENT NON TRACKING IMPACT

Impact Speed (mph) 56

$$\text{Impact Speed} = \frac{60}{88} * \sqrt{\frac{(\underset{\text{CSI}}{40000} * 2 * 32.2)}{\underset{\text{weight}}{[illegible]}}} \Big/ \sin(\underset{\text{impact angle}}{22})$$

Instructions:

1. Enter date stamped on envelope and the psu and case numbers under Identification.
2. Enter vehicle information from Vehicle Data Form for vehicle No. 1 only.
3. Enter guardrail information from Longitudinal Barrier Data Form for first impact only.
4. Enter accident information from Longitudinal Barrier Data Form for first impact only. Multiply permanent deflection by appropriate factor and enter as dynamic deflection.
5. Confirm vehicle, barrier, and accident information with slides. Correct inconsistencies by drawing a single line through original value and writing correct value next to strike-out. Estimate impact angle from tire marks and/or vehicle placement marker in slides if available and from accident sketch.
6. Using the dynamic deflection, determine the CSI from the appropriate graph for this type of barrier.
7. Calculate impact speed using the equation provided. Enter appropriate numbers from this sheet in the shaded areas.

Name: Ade Avdiffen Date: 11/09/90 Ckd: ________

Figure 3. Sample reconstruction worksheet.

Case No. 03-502C Date '86 CSS ______ LSS ✓

[✓ Guardrail] Median Barrier [✓ Terminal] [✓ Shoulder] Median Island/Gore

Barrier/Terminal Type G4(1S) TURNDOWN

Site Features: Direction of Slope ______ Shoulder/Median Width ______ ft Curb 3" Other ______

Impact Conditions: Vehicle Weight 4069 lbs Est. Speed 52 mph Impact Angle 6 deg Yaw Angle 9 deg

Barrier Performance:
Redirected ____ Snagged/Pocketed ____ Overrode ✓ Vaulted ____ Penetrated ____ Rollover ____

Barrier Contact Distance 90 ft Separation Distance to Final Rest Point 0 ft

Injury Severity: Police Report NONE, AIS Numbers (1-7)

PDO (0) ✓ Minor (1) ____ Moderate (2) ____ Severe (3) ____ Serious (4) ____ Critical (5) ____

Untreatable (6) ____ Unknown (7) ____

Highest Delta "V": Imp #(1) G.R. END Imp #(2) GROUND Imp #( ) ______

Brief Description: VEHICLE MOUNTED TURNDOWN - CONTINUED ON TOP OF BARRIER FOR FT GAS TANK RUPTURED & VEHICLE BURNED.

Burned Guardrail

Total Inside Burned Outside Burned

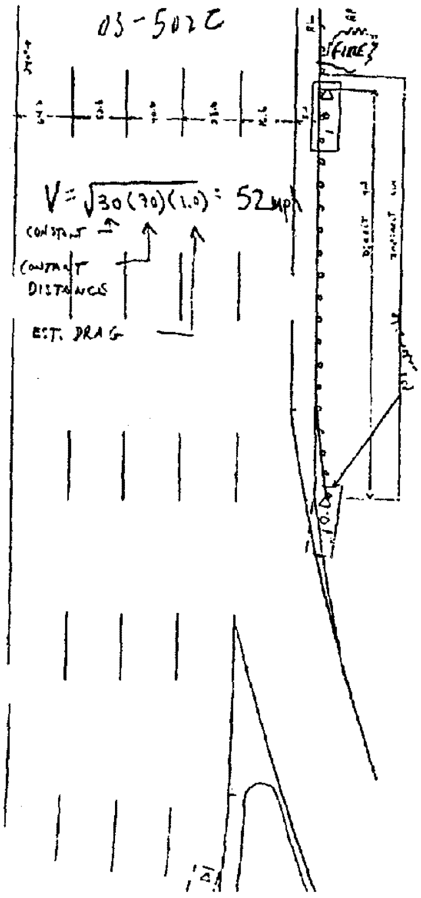
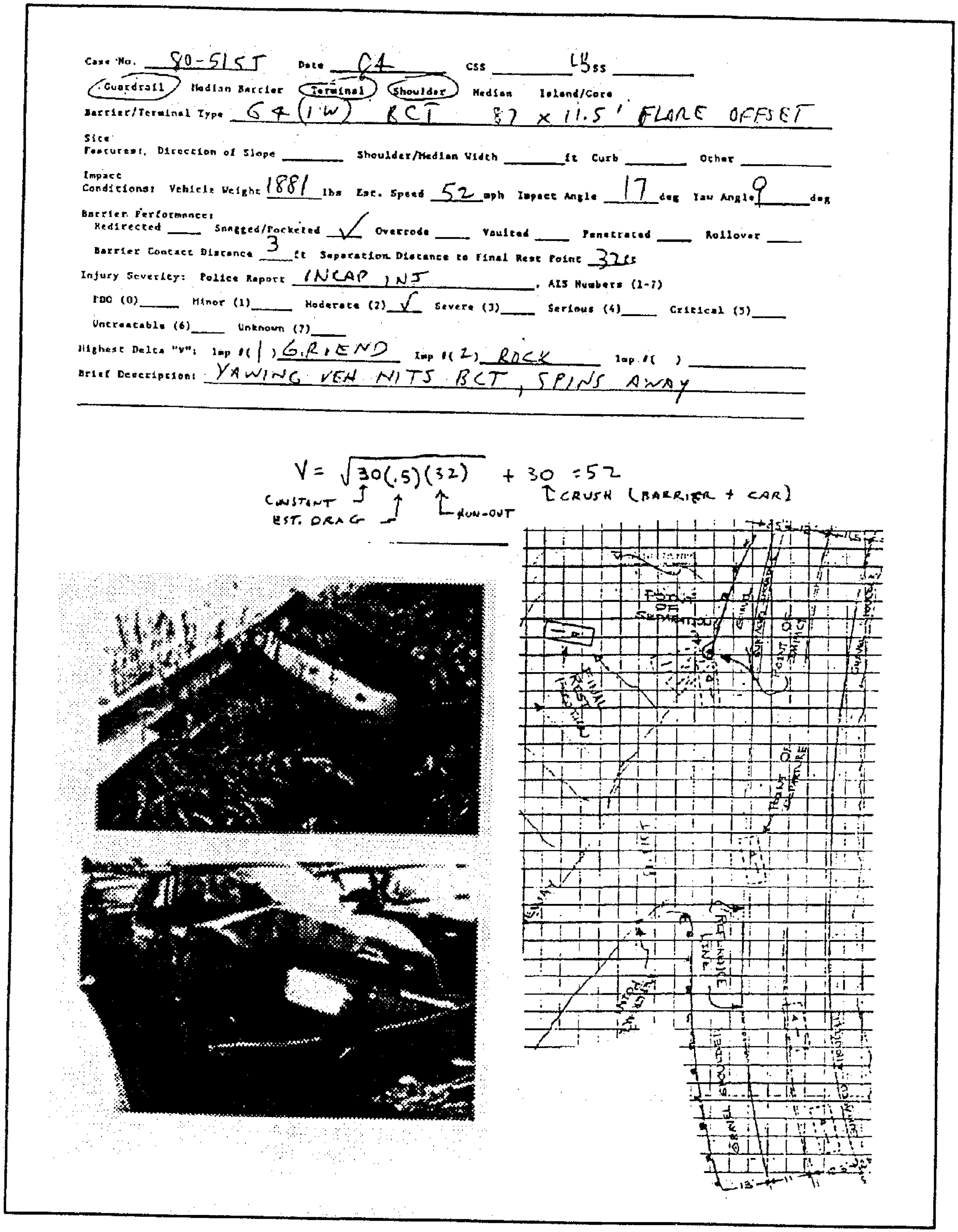


Figure 4. Estimated speed from vehicle drag and trajectory.



Case No. 80-515T Date C4 CSS L5SS

[✓ Guardrail] Median Barrier [✓ Terminal] [✓ Shoulder] Median Island/Core

Barrier/Terminal Type G4 (1W) BCT 87 × 11.5' FLARE OFFSET

Site Features, Direction of Slope ____ Shoulder/Median Width ____ ft Curb ____ Other ____

Impact Conditions: Vehicle Weight 1881 lbs Est. Speed 52 mph Impact Angle 17 deg Yaw Angle 9 deg

Barrier Performance:
Redirected ____ Snagged/Pocketed ✓ Overrode ____ Vaulted ____ Penetrated ____ Rollover ____

Barrier Contact Distance 3 ft Separation Distance to Final Rest Point 32 ft

Injury Severity: Police Report INCAP INJ, AIS Numbers (1-7)

PDO (0) ____ Minor (1) ____ Moderate (2) ✓ Severe (3) ____ Serious (4) ____ Critical (5) ____

Untreatable (6) ____ Unknown (7) ____

Highest Delta "V": Imp #(1) G.R. END Imp #(2) ROCK Imp #( ) ____

Brief Description: YAWING VEH HITS BCT, SPINS AWAY

$$V = \sqrt{30(.5)(32)} + 30 = 52$$

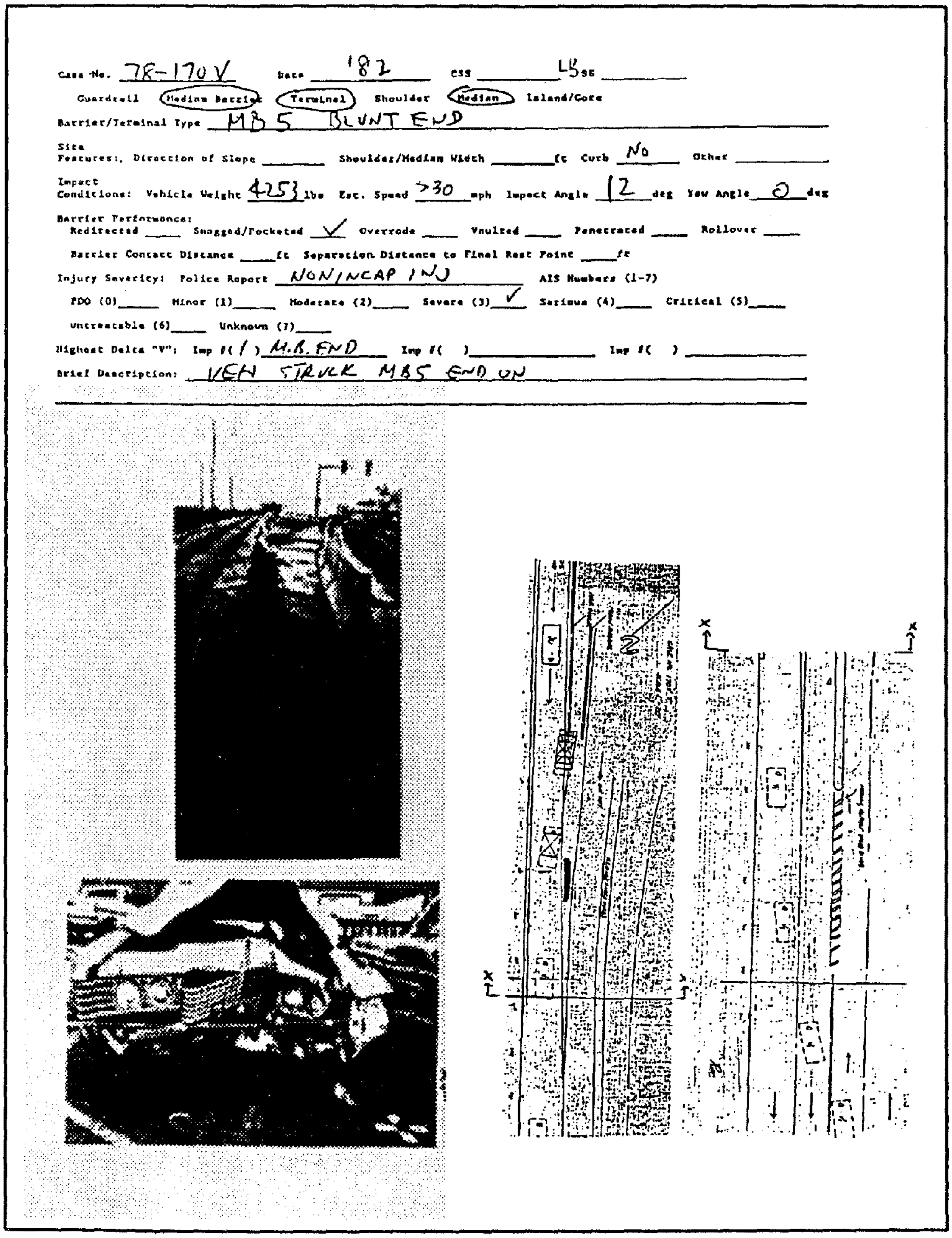
CONSTANT

EST. DRAG

RUN-OUT

CRUSH (BARRIER + CAR)

Figure 5. Estimated speed from vehicle crush/trajectory/run-out calculations.



Case No. 78-170V Date '82 CSS LB SB

Guardrail [✓ Median Barrier] [✓ Terminal] Shoulder [✓ Median] Island/Gore

Barrier/Terminal Type MBS BLUNT END

Site Features:, Direction of Slope ______ Shoulder/Median Width ______ft Curb No Other ______

Impact Conditions: Vehicle Weight 4253 lbs Est. Speed >30 mph Impact Angle 12 deg Yaw Angle 0 deg

Barrier Performance:

Redirected ____ Snagged/Pocketed ✓ Overrode ____ Vaulted ____ Penetrated ____ Rollover ____

Barrier Contact Distance ____ft Separation Distance to Final Rest Point ____ft

Injury Severity: Police Report NON/INCAP INJ AIS Numbers (1-7)

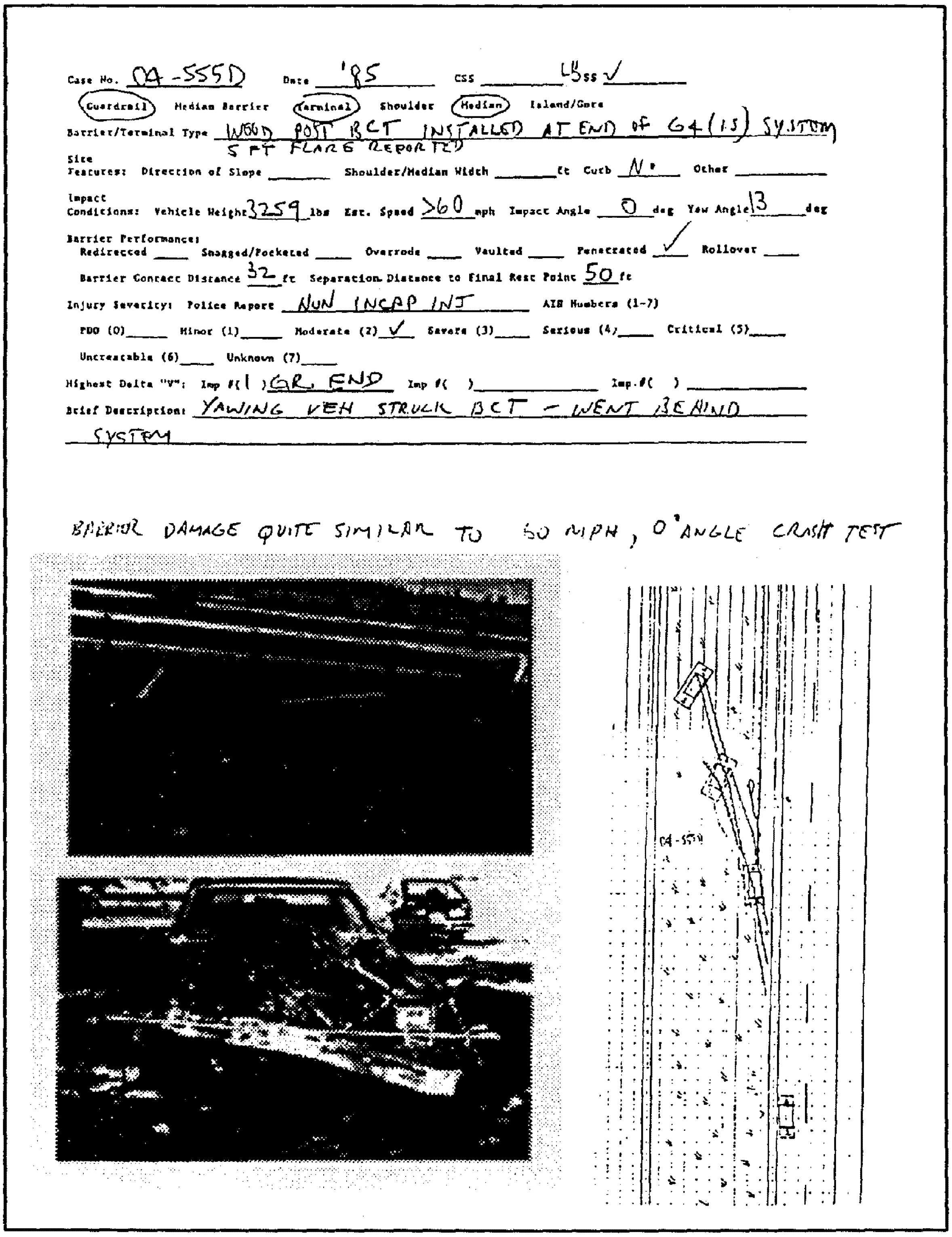
PDO (0)____ Minor (1)____ Moderate (2)____ Severe (3) ✓ Serious (4)____ Critical (5)____

Untreatable (6)____ Unknown (7)____

Highest Delta "V": Imp #(/) M.B. END Imp #( ) ______ Imp #( ) ______

Brief Description: VEH STRUCK MBS END ON

Figure 6. Estimated speed based on vehicle damage/occupant injury.



Case No. 04-555D Date '85 CSS LBss ✓

[✓ Guardrail] Median Barrier [✓ Terminal] Shoulder [✓ Median] Island/Gore

Barrier/Terminal Type WOOD POST BCT INSTALLED AT END OF G4(1S) SYSTEM
5 FT FLARE REPORTED

Site Features: Direction of Slope ____ Shoulder/Median Width ____ ft Curb N° Other ____

Impact Conditions: Vehicle Weight 3259 lbs Est. Speed >60 mph Impact Angle 0 deg Yaw Angle 13 deg

Barrier Performance:
Redirected ____ Snagged/Pocketed ____ Overrode ____ Vaulted ____ Penetrated ✓ Rollover ____

Barrier Contact Distance 32 ft Separation Distance to Final Rest Point 50 ft

Injury Severity: Police Report NON INCAP INJ AIS Numbers (1-7)

PDO (0)____ Minor (1)____ Moderate (2) ✓ Severe (3)____ Serious (4)____ Critical (5)____

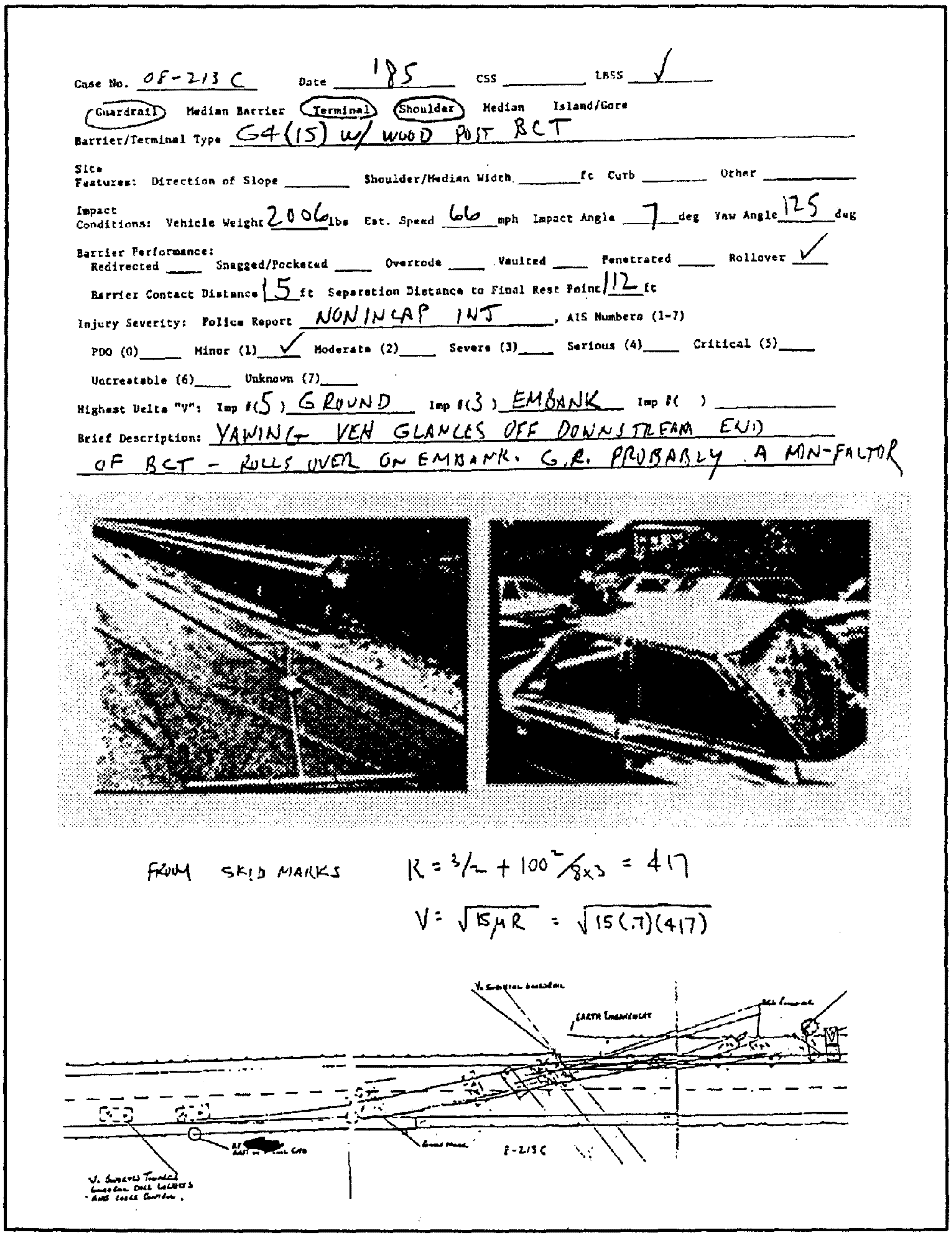
Untreatable (6)____ Unknown (7)____

Highest Delta "V": Imp #(1) GR. END Imp #( )____ Imp.#( )____

Brief Description: YAWING VEH STRUCK BCT - WENT BEHIND SYSTEM

BARRIER DAMAGE QUITE SIMILAR TO 50 MPH, 0° ANGLE CRASH TEST

Figure 7. Estimated speed from crash test experience.



Case No. 0F-213 C Date 185 CSS ____ LBSS ✓

[✓ Guardrail] Median Barrier [✓ Terminal] [✓ Shoulder] Median Island/Gore

Barrier/Terminal Type G4(15) w/ WOOD POST BCT

Site Features: Direction of Slope ____ Shoulder/Median Width ____ ft Curb ____ Other ____

Impact Conditions: Vehicle Weight 2006 lbs Est. Speed 66 mph Impact Angle 7 deg Yaw Angle 125 deg

Barrier Performance:
Redirected ____ Snagged/Pocketed ____ Overrode ____ Vaulted ____ Penetrated ____ Rollover ✓

Barrier Contact Distance 15 ft Separation Distance to Final Rest Point 112 ft

Injury Severity: Police Report NONINCAP INJ, AIS Numbers (1-7)

PDO (0)____ Minor (1) ✓ Moderate (2)____ Severe (3)____ Serious (4)____ Critical (5)____

Untreatable (6)____ Unknown (7)____

Highest Delta "V": Imp #(5) GROUND Imp #(3) EMBANK Imp #( ) ____

Brief Description: YAWING VEH GLANCES OFF DOWNSTREAM END OF BCT - ROLLS OVER ON EMBANK. G.R. PROBABLY A MIN-FACTOR

FROM SKID MARKS $R = 3/2 + 100^2/8\times3 = 417$

$V = \sqrt{15\mu R} = \sqrt{15(.7)(417)}$

Figure 8. Speed estimate based on yaw marks prior to barrier collision.

Discussion

The speed data reconstructions performed under this study were performed using the principle of energy conservation. The procedures used, however, required making several assumptions. These assumptions included an examination of occupant weights in the vehicle weight and categorizing curved rails, with a degree of curvature less than 6°, as straight. Also, the impact speeds for accidents involving a series of events too complicated to analyze were based on an expert's crash test experience. These speeds were usually engineering estimates.

While reconstructing impact speeds, it was discovered that results obtained for certain cases differed from those obtained for the same cases reconstructed under a separate FHWA research study performed by the Texas Transportation Institute (TTI).[3] A comparison of the two results was made in an attempt to ascertain the reason for the differences.

A sample of 25 (all involving concrete barriers) common to both studies was reviewed. The results are detailed in table 3. With results from the TTI study rounded to the nearest multiple of 5, table 3 shows both sets of results as being within 10 mi/h (16.1 km/h) of each other for 72 percent of the cases. The results are, however, significantly different in the remaining 28 percent [as different as 35 mi/h (56.4 km/h) in one instance].

A second review of the cases involving differences of greater than 10 mi/h (16.1 km/h) - cases bold-faced in table 3 - was performed to check for any errors that might have occurred in the initial calculations. In two of those cases (specifically, 82-81-503W and 82-82-571W), the original assessments were revised and the new results agreed with those from the TTI study. For case 82-82-571W, some pages in the accident sketch had been accidentally omitted. For case 82-81-503W, the initial review assumed brakes were not applied prior to impact; the second review determined that brakes had actually been applied. The other five cases were found to be without error.

An independent accident expert was asked to reconstruct the same cases in an attempt to determine if the results obtained would be similar to any of the previous two sets. Those results are shown in table 4. The accident expert's results seemed to lie between the first two sets.

The conclusion of the independent expert was that the differences in the initial results might have resulted from how braking distance was determined. Braking distance is critical to the drag factor that is used in determining impact speeds.

The fact that three reviewers using similar procedures could obtain different, albeit legitimate, results demonstrates the limits of current reconstruction techniques. It should be noted, however, that modifying table 4 to show agreement on cases 82-81-503W and 82-82-571W, yields 80 percent of the results within 10 mi/h (16.1 km/h) of each other. Also, the sample used in making this comparison was a small one and a better comparison might have been possible with a larger sample.

This matter is worth additional study to obtain a better understanding of longitudinal barrier crash speeds.

Table 3. Comparison of impact speed reconstructions.

Case	TTI*	Review-A**	Diff.
82-02-510V	40 mi/h	30 mi/h	-10
82-02-520V	55	45	-10
82-30-506W	15	15	0
82-55-504W	30	40	10
82-79-514W	65	60	-5
82-80-504Y	**25**	**40**	**15**
82-80-518Z	20	10	-10
82-81-503W	**40**	**20**	**-20**
82-82-507Z	15	15	0
82-82-536W	20	30	10
82-82-556T	40	35	-5
82-82-559W	20	30	10
82-82-571W	**70**	**55**	**-15**
82-82-573W	35	30	-5
82-82-574T	60	55	-5
83-02-510W	**25**	**60**	**35**
83-03-519T	55	55	0
83-03-525W	50	45	-5
83-04-505W	30	30	0
83-04-509R	**20**	**40**	**20**
83-04-510W	**20**	**40**	**20**
83-04-514V	**35**	**55**	**20**
83-10-506W	15	25	10
83-30-519V	45	40	-5
83-80-518Z	40	30	-10

* Data from TTI study rounded to the nearest 5 mi/h.

** Review-A - represents results from initial reconstructions.

1 mi/h = 1.61 km/h

Table 4. Comparison of initial speeds with independent expert's results.

Case	TTI*	Review-A**	Review-B***
82-02-520V	55 mi/h	45 mi/h	45 mi/h
82-80-504Y	25	40	45
82-82-533R	-	25	25
83-02-510W	25	60	>60
83-03-523W	-	45	-
83-04-509R	20	40	35
83-04-510W	20	40	30
83-04-514V	35	55	35

* TTI - results from TTI study.
** Review-A - results from initial reconstructions.
*** Review-B - results from independent expert.

1 mi/h = 1.61 km/h

III. ANALYSIS OF THE SEVERITY OF BARRIER LENGTH OF NEED VS. BARRIER END IMPACTS

INTRODUCTION

For roadway/roadside design engineers and others interested in the performance of hardware, persistent topics of interest have been:

- The performance of various types of guardrails, median barriers, and end treatments.
- The comparison of risk to the driver when striking a barrier length of need (LON) vs. a barrier end section.

These topics were explored using the Longitudinal Barrier Special Studies (LBSS) file.

CREATION OF THE ANALYSIS FILE

The main analysis file for the questions related to barrier and end types and risk in LON vs. end crashes is a vehicle-oriented file, built from several subfiles, with one record per vehicle. The analysis file was developed from an original accident-oriented file that contained information on all impacts by all vehicles involved in a crash and the object contacted for each impact. The file was first restricted to only single-vehicle accidents. Analysis of the first year of LBSS cases (1982), during the data collection period, showed vehicle-to-vehicle contacts to consistently be the most harmful event in multiple-vehicle cases. These cases are of little interest in this LBSS study. Consequently, only single vehicle cases were selected for the LBSS from mid-1982 on. The deletion of multiple-vehicle accidents converted the original file into a file containing one record per vehicle. Second, a separate impact-oriented file, which represents a record per impact, was combined with the vehicle-oriented file. Third, an occupant subfile (containing injury information for the driver and right front passenger in each vehicle) was merged with the appropriate vehicle record in the analysis file. Finally, 168 variables on the merged file were selected as candidates for analysis from the accident, vehicle, occupant, driver, contacts, and impacts subsets.

The analysis file also contained a "flag" variable that allowed it to be categorized into three types of analysis records, all of which involve single-vehicle crashes: (1) an "all hits" file, in which a vehicle struck a barrier whether or not another barrier or object was struck, (2) a "barrier hits only" subfile, in which a vehicle struck no objects other than one or more longitudinal barriers, and (3) a "clean hits" subfile, in which a vehicle struck only a single barrier, though sometimes more than once. Thus, using the "clean hits" subfile, the instances where a vehicle struck a barrier and nothing else, or the vehicle struck the same barrier several times, could be examined.

The "barrier hits only" and "clean hits" subfiles are contained within the "all hits" file. The analyses conducted utilized the "clean hits" and "all hits" data. Using the "clean hits" data was felt to be the most appropriate way to examine harm caused by a specific barrier

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type, in that any driver injury would be the result of striking the barrier. If a vehicle struck another vehicle or object and then a barrier, determining when the injury occurred would be somewhat speculative even for trained investigators. Thus, for most of the analyses, the "clean hits" subfile was used to verify the results from the larger "all hits" file. The "clean hits" subfile resulted in a total of 665 vehicle records; the "barrier hits only" subfile, 971 vehicles; and the "all hits" file, 1,062 vehicles.

THE NATURE OF THE "CLEAN HITS" SUBFILE

Because much of the analyses involved the "clean hits" subfile, the following text provides brief highlights from some of the variables on this file as an overview of the nature of the data analyzed. Results from the "all hits" file were quite similar. From the "clean hits" data, 665 single-vehicle impacts were available, 450 pertaining to LON, and 215 to barrier-end crashes (barrier-end crash is defined as an impact occurring within the first 25 ft (7.62 m) of the barrier). The percentages shown below are based on the total 665 impacts and cover only the major classifications examined within each variable; thus they do not always total 100.

- Guardrail types - 23 percent G4 (lS) (blocked-out W-beam with steel posts), 20 percent W-beam strong post.
- Median barrier types - 58 percent concrete median barrier.
- Blocked-out presence - 55 percent blocked out.
- End treatment type - 41 percent blunt, 30 percent turndown, 10 percent breakaway cable.
- Location of end treatment in direction of vehicle travel - 78 percent upstream (i.e., the first end a vehicle would encounter in normal direction of travel).
- Distance from end of barrier to initial point of impact - 21 percent within first 10 ft (3 m).
- Length of longitudinal barrier section - 87 percent longer than 100 ft (30 m).
- Location of barrier in direction of vehicle travel - 61 percent off left side of road, 36 percent off right side. (When the item was coded, guardrail crashes split as 44 percent off of left side and 56 percent off of right side.)
- Curb presence - 16 percent of time present.
- Curb height - 61 percent, 1 to 5 in (25 to 127 mm); 39 percent, 6 to 10 in (152 to 254 mm).
- Perpendicular distance from curb to barrier - 62 percent, 3 ft (1 meter) or less.

- Total change in elevation - 13 percent no change, 57 percent below edge of roadway, 30 percent above edge of roadway. (For LON, virtually the same percentages; ends, 12 percent no change, 67 percent below edge of roadway, 21 percent above edge of roadway.)

- Longitudinal barrier height - 32 percent, 26 to 29 in (660 to 737 mm) in height; 30 percent, 30 to 33 in (762 to 838 mm) in height. (For LON, 29 percent, 26 to 29 in (660 to 737 mm) in height; 36 percent, 30 to 33 in (762 to 838 mm) in height. For ends, 38 percent, 26 to 29 in (660 to 737 mm) in height; 17 percent, 30 to 33 in (762 to 838 mm) in height.)

- Total horizontal distance to barrier - 3 percent, barrier at edge of road; 22 percent, 1 to 4 ft (0.3 to 1.2 m) from edge; 26 percent, 5 to 8 ft (1.5 to 2.4 m) from edge; 29 percent, 9 to 12 ft (2.7 to 3.7 m) from edge; and 20 percent, 13 ft (4 m) and greater from edge.

- Length of direct contact with barrier - 63 percent, 1 to 20 ft (0.3 to 6.1 m) of contact; 27 percent, 21 to 50 ft (6.4 to 15.3 m) of contact.

- Impact angle - 1 percent at zero degrees, 21 percent at 1 to 8 degrees. (For LON, 1 percent at zero degrees and 15 percent at 1 to 8 degrees. For ends, 3 percent at zero degrees and 24 percent at 1 to 8 degrees.)

- Yawing angle at impact - 4 percent at zero degrees, 14 percent at 1 to 8 degrees, 32 percent greater than 27 degrees. (For LON, 3 percent at zero degrees, 11 percent at 1 to 8 degrees, 31 percent greater than 27 degrees. For ends, 5 percent at zero degrees, 22 percent at 1 to 8 degrees, 33 percent greater than 27 degrees.)

- Impact speed - 36 percent at 21 to 35 mi/h (34 to 56 km/h), 30 percent at 36 to 45 mi/h (58 to 72 km/h), 12 percent at 46 to 55 mi/h (74 to 89 km/h), and 9 percent greater than 55 mi/h (89 km/h). (For LON and ends separately, virtually the same percentages.)

- Separation angle - 63 percent at zero to 8 degrees. (For LON and ends separately, virtually the same percentage.)

- Barrier performance - 65 percent redirected, 11 percent snagged, 12 percent overrode. (For LON, 77 percent redirected, 9 percent snagged, 7 percent overrode. For ends, 38 percent redirected, 16 percent snagged, 22 percent overrode.)

- Post-impact trajectory - 50 percent remained on roadside, 25 percent returned to roadway, 16 percent on top of/over/through. (For LON, 52 percent remained on roadside, 28 percent returned to roadway, 11 percent on top of/over/through. For ends, 47 percent remained on roadside, 18 percent returned to roadway, 25 percent on top of/over/through.)

- Subsequent impact - 10 percent rollover (9 percent for LON and 13 percent for ends).

- Driver age - 0.3 percent less than 16 years of age; 22 percent, 16 to 20 years of age; 20 percent, 21 to 24 years of age; 31 percent, 25 to 35 years of age; 20 percent, 36 to 55 years of age; 5 percent, 56 to 75 years of age; 1 percent, 76 years of age and over.

- Driver injury, MAIS scale - 40 percent, no injury; 45 percent, minor injury; 9 percent, MAIS 3 and above. (For LON, 42 percent, no injury; 48 percent, minor injury; 3 percent, MAIS 3 and above. For ends, 40 percent, no injury; 43 percent, minor injury; 11.5 percent, MAIS 3 and above.)

- Driver injury, KABCO scale - 51 percent, no injury; 12 percent, possible or C injury; 24 percent, non-incapacitating or B injury; 11 percent, incapacitating or A injury; 0.8 percent, killed. (For LON, 52 percent, no injury; 12 percent, C injury; 24 percent, B injury; 10 percent, A injury; and 0.7 percent, killed. For ends, 48 percent, no injury; 10 percent, C injury; 23 percent, B injury; 18 percent, A injury; 1.4 percent, killed.)

- Vehicle type - 83 percent passenger cars, 15 percent light trucks and vans, and 3 percent heavy trucks.

REPRESENTATIVENESS OF THE LBSS FILE

Due to the nature of the questions that can be analyzed with the LBSS file, it is important to have some understanding as to how "representative" the file is of barrier impacts in the U.S. The LBSS file cannot be used for determining frequency or rate of barrier impacts, so questions concerning representativeness are related to the severity of the crash.

To examine the issue of representativeness, information was extracted from accident files from the States of North Carolina, Michigan, Utah, Maine, and Illinois. The last four States are part of the Highway Safety Information System (HSIS), the FHWA data base being used in many of their internal analyses. North Carolina files were used because: (1) they were available to the researchers, (2) the files have been shown to be quite complete and accurate in past research efforts, (3) "towaway" crashes can be identified, and (4) information is available on location of barrier impact (i.e., end vs. LON).

Because the LBSS file was developed as part of the National Accident Sampling System (NASS), the longitudinal barrier impacts investigated were, to a significant degree, "towaway" crashes. In the file used in these analyses, approximately 14 percent were non-towaway vehicles. In contrast, in North Carolina's total file (including both towaway and non-towaway crashes), over 65 percent of the vehicles could be "safely driven" from the crash scene. For this reason, the primary comparison States used were North Carolina and Michigan and data were screened on a variable related to "drivability of vehicle." Thus, in both these States, only those vehicles that were cited as "not drivable from scene" were used in the analysis. Thus, the comparisons include two "towaway" States (i.e., North Carolina and Michigan) and three States (i.e., Utah, Maine, and Illinois) that included both towaway and non-towaway vehicles.

The LBSS file used in these comparisons was the "all hits" file, which included all crashes in which the first impact was into a barrier (thus including, but not limited to, the "clean hits" subfile). For each of the comparison States, an attempt was made to use several variables in the accident and vehicle subfiles to limit the impacts being studied to those in which: (1) a guardrail or median barrier was the fixed object struck, (2) the guardrail impact was the most harmful event, and (3) all impacts were single vehicle accidents. This latter criteria eliminated cases where two vehicles would impact each other and then rebound into a barrier, as well as cases in which a vehicle would hit the barrier and then rebound into another vehicle. Because some of the States' data files did not include a "most harmful event," this attempt was not always successful. However, even in these cases, data was limited to cases involving guardrails/median barriers and single vehicle crashes.

In all the comparison States, data for barrier impacts were combined for the calendar years 1985 and 1986. Although the LBSS file includes impacts occurring during 1982 through 1986, the HSIS system did not include data prior to 1985. Therefore, 1985 and 1986 LBSS data was used and compared with similar year HSIS North Carolina data. One would not expect significant differences between these two time periods in either the crash characteristics or the makeup of guardrails on the roadside. Thus, the comparisons appear valid.

The results of this analysis are shown in tables 5, 6, and 7 on the following pages. Table 5 depicts information on four variables related to the driving environment -- road class, road condition, speed limit, and weather -- and one variable related to the location of impact on the barrier (end vs. LON). Table 6 provides information related to two vehicle-related variables -- vehicle type and impact speed. Table 7 provides information on three variables related to the vehicle drivers -- driver injury, driver age, and driver sex. The total sample size for each State is shown at the top of each column and each cell contains the distribution of percentages for categories within each data element (variable). An asterisk in a cell indicates a significant number of missing observations.

A study of the tables indicates the following. With respect to the road class variable (where comparison data were only available from North Carolina and Michigan), the LBSS file was most similar to North Carolina (see table 5). The LBSS file contained a lower percentage of impacts on Interstates and a higher percentage of impacts on county and local roads and streets than did the Michigan file.

With respect to road condition, the LBSS file had a higher proportion of impacts on dry pavement and a much lower proportion on snowy or icy pavements than the remaining States. Again, the LBSS file was most similar to the North Carolina towaway file. It was very different from the Michigan towaway file that was characterized by a high percentage of snow and ice-related accidents and a relatively low percentage of dry roadway accidents.

Table 5. LBSS/State percentage comparisons for roadway variables.

	LBSS (1062)†	NC Towaways (1618)	Michigan Towaways (9251)	Utah (1117)	Maine (1925)	Illinois (6099)
Road Class						
Interstate	42.5	35.1	61.4			
U.S.	12.8	28.7	21.5			
State	21.4	13.8	15.1			
County	9.8	10.2	-			
Local Street	12.5	11.1	-			
Other	0.8	0.5	2.0			
Road Condition						
Dry	65.8	59.6	42.1	50.4	39.6	51.4
Wet	22.8	29.7	23.8	14.2	13.6	26.8
Snow/Ice	11.2	11.2	33.9	35.4	46.0	20.6
Sand/Dirt/Other	0.3	0.2	0.3	0.1	0.8	0.6
Speed Limit (mi/h)				*		
15	0.1	0.2		0.4	0.2	
20	0.7	0.5		0.6	0.5	
25	4.4	0.9		2.6	7.8	
30	4.8	0.3		3.5	3.8	
35	9.6	10.8		3.6	14.0	
40	6.3	0.3		4.7	3.1	
45	8.3	13.3		3.1	15.7	
50	6.9	1.6		5.4	12.4	
55	58.9	72.0		65.7	39.3	
60						
65						
Weather						
Clear/Cloudy	74.1	66.8	62.1	69.7	55.0	64.1
Rain	17.3	27.6	16.9	7.6	11.8	20.3
Sleet/Snow	7.3	3.9	20.1	17.5	29.8	12.2
Fog/Other	1.3	1.7	0.9	5.0	3.2	1.6
Impact Point						
Length of Need	70.8	76.3				
Upstream End	29.2	23.7				

† Values in ( ) equal number of total cases in designated file.
* Cell contains a significant number of cases with missing observations.
1 mi/h = 1.61 km/h

In terms of speed limit, there were only minor differences between the LBSS file and the comparison States, but the LBSS file had slightly fewer impacts on roadways with a 55 mi/h (88 km/h) speed limit (except for the case of Maine). However, the difference was not great.

Examining weather, as was reflected in road condition codes, the LBSS file had the highest proportion of clear or cloudy weather and the lowest proportion of sleet or snow.

The final variable in table 5 is related to the barrier impact point location -- whether the impact was with the end of the rail or within the LON. Here it was only possible to compare the LBSS file to the North Carolina file since none of the other States' accident files had such information. The LBSS file had a slightly higher percentage of impacts into the end of the barrier (29.2 percent vs. 23.7 percent). In these cases, LON in the LBSS file was defined as LON plus "downstream ends." This would appear to provide the best comparison given the fact that officers in North Carolina were more likely to define an impact when the end is the first encountered in the normal flow of traffic -- the "upstream" end.

Variables related to vehicle are found in table 6. The vehicle type data indicate that the LBSS was similar to both towaway States (North Carolina and Michigan) and to Illinois. The LBSS file contained a higher proportion of passenger cars than either Utah or Maine. It also contained a lower proportion of heavy trucks, and no motorcycles. One finding of particular interest is that Utah had a much higher proportion of pickup trucks than either the LBSS file or the other comparison States.

Comparisons of impact speed could only be made between the LBSS file and files from North Carolina and Utah. While impact speeds were at least partially the result of crash reconstructions in the LBSS file, and thus should be quite accurate, speeds in the North Carolina and Utah files were only estimates made by investigating officers. Although the distributions are somewhat similar, the major portion of the reconstructed speeds in the LBSS file fell between 20 and 50 mi/h (32 and 81 km/h), while the major portion of the other two files fell between 30 and 60 mi/h (48 and 97 km/h).

Table 7 presents the comparison information for the driver-related variables. First, there is little difference in the driver age or driver sex characteristics in the LBSS file vs. any of the comparison State files. Still, the Michigan file has a slightly lower percentage of 16- to 20-year-old drivers and a slightly higher percentage of 36- to 55-year-old drivers. However, these relatively minor differences would not be expected to result in injury outcome differences.

However, with the most important variable -- driver injury -- there are differences even in the most similar North Carolina towaway file. The major difference is that the LBSS file has almost twice the percentage of fatal driver injuries (1.7 percent in the LBSS vs. 0.8 percent in North Carolina, and 0.4 percent, 0.8 percent, 0.5 percent, 0.7 percent, respectively in the other States). The LBSS file also has a slightly higher percentage of drivers experiencing "A" injuries when compared to North Carolina and Illinois, and the difference is even larger in comparison to "A" injuries in Michigan, Utah, and Maine.

While similar to North Carolina in terms of "no injury" cases, the LBSS percentage is somewhat lower than in Michigan, and much lower than for Utah, Maine, or Illinois. While this is not surprising for the non-towaway States (where one would expect a much higher proportion of minor collisions being reported), the distribution of Michigan driver injury is somewhat surprising, given its "towaway" requirement. Michigan barrier impacts result in a lower fatal percentage than do any of the other States, and a higher "no injury" percentage than LBSS or North Carolina. It might be first hypothesized that this difference could result from the higher proportion of impacts on Interstate highways (see table 5), given that the overall severity of injury might be lower since barriers on Interstates might be of higher design than the barriers on the other classes of roads. However, a cross tabulation of "driver injury" by "road class" only indicated such a trend to a limited degree. The percentage of fatal impacts on Interstates is lower than for other classes of highway, but the percentage "not injured" is similar across roadway classes, except for "Other State Trunk Highways," which surprisingly, has a higher percentage of "not injured" cases than the Michigan Interstates (70.7 percent vs. 56.7 percent).

Table 6. LBSS/State percentage comparisons for vehicle variables.

	LBSS (1062)†	NC Towaways (1618)	Michigan Towaways (9251)	Utah (1117)	Maine (1925)	Illinois (6099)
Vehicle Type						
Passenger Car	83.8	78.4	82.4	69.9	73.9	81.2
Pickup/2-, 3- Axle Truck	11.5	13.1	11.1	22.5	16.7	8.9
Van	2.6	-	-	-	1.9	3.0
Tractor Trailer /Twin	1.9	6.2	5.1	4.5	2.9	5.1
Motorcycle	-	1.7	0.6	2.3	1.4	1.5
Other	0.2	0.5	0.8	0.9	0.3	0.5
Impact Speed (mi/h)	*			*		
1-9	0.2	0.7		3.5		
10-19	6.1	2.3		9.9		
20-29	20.2	10.4		15.6		
30-39	26.9	21.6		21.3		
40-49	25.9	30.2		24.1		
50-59	11.1	25.3		18.2		
60-69	6.9	5.2		6.0		
70-79	1.5	1.5		1.2		
80-89	0.6	0.9		0.2		
90-99	0.8	0.1		0.1		
100+						

† Values in ( ) equal number of total cases.
* Cell contains significant number of missing observations.
1 mi/h = 1.61 km/h

A second hypothesis for the less severe injury distribution in Michigan relates to the higher number of accidents that occurred on roadways with snow or ice. Many vehicles reported as being "towaway" in Michigan could be vehicles that were towed simply because they were involved in a crash in an environment consisting of snow and ice, rather than because of the severity of the impact itself. Indeed, a cross tabulation of "Driver Injury" by

"Road Surface Condition" indicated this to be at least a partial explanation. Here, the percentage of fatal incidents ranges from 0.7 percent on dry roads (similar to North Carolina) to 0.1 percent on snowy/icy roads. In a like fashion, the percentage of "no injury" incidents ranges from only 46.9 percent on dry roads to 65.8 percent on snowy/icy roads. In general, Michigan "towaway" barrier crashes are not as severe as either LBSS or North Carolina crashes, and part of the difference appears to be related to the high proportion of impacts on snowy/icy roads.

It is also noted that the LBSS injury distribution may be slightly more severe than in the comparison States due to lower occupant restraint use in the LBSS files. In four of the comparison States (North Carolina, Michigan, Illinois, and Utah), mandatory belt laws were passed in 1985 and 1986. While the major effect of these laws was not seen until later years because the publicity associated with the passage of the law appeared to have affected belt use in many States, one would expect that the average usage rate for these comparison States would have been higher than the average rate for the 1982 through 1986 LBSS file. Unfortunately, due to what appears to be significant increases in the "lie factor" in States with laws (i.e., inaccurate statements regarding usage by the crash-involved occupants),

Table 7. LBSS/State percentage comparison for driver variables.

	LBSS (1062)†	NC Towaways (1618)	Michigan Towaways (9251)	Utah (1117)	Maine (1925)	Illinois (6099)
Driver Injury				*		
No	47.6	49.9	55.8	68.6	71.7	63.7
C	11.5	18.2	17.9	8.6	11.6	9.8
B	25.2	19.1	16.9	13.1	12.6	13.7
A	13.5	11.9	9.0	8.9	2.8	12.1
K	1.7	0.8	0.4	0.8	0.5	0.7
Driver Age				*		
Less than 16	0.3	0.6	0.0	0.5	0.6	2.4
16-20	22.5	24.2	17.8	23.0	21.1	17.4
21-24	19.7	20.5	21.6	17.1	19.4	18.9
25-35	30.8	28.2	28.6	31.7	28.9	32.3
36-55	20.6	20.3	23.9	21.3	21.2	22.1
56-75	5.4	5.6	8.1	5.8	7.5	6.4
76+	0.6	0.7		0.6	1.2	0.6
Driver Sex				*		
Male	68.6	70.3	66.3	65.0	65.9	68.8
Female	31.4	29.7	33.7	35.0	34.1	29.8

† Values in ( ) equal number of total cases.

* Cell contains significant number of missing observations.

belt use in police-reported crashes has been shown to be greatly inflated when compared to observational data. Thus, there is no way to accurately compare the average belt use of the LBSS and comparison State samples.

Finally, in contrast with the above effects, the severity of barrier crashes in the LBSS file might be hypothesized to be slightly **lower** than in the comparison States due to the exclusion of motorcycle crashes from LBSS investigations (see table 6). While the total proportion of motorcycle impacts into barriers is quite low in each of the comparison States, there is reason to believe that a motorcycle crash into a barrier would be a very high severity event, with death and/or severe injury occurring in almost 50 percent of the crashes.[9] Thus, if motorcycle crashes had been included in the LBSS file, one might have expected a slightly more severe distribution than what is shown, at least for fatal injury.

In summary, fatal driver injuries occurred almost twice as often in the LBSS file than in all other files, and serious injury occured slightly more often than in the North Carolina towaway file and significantly more often than in the Michigan towaway file and in the other States. This may be partially due to lower seat belt usage rates in the LBSS file, and partially due to the good driving conditions and environment that were found within that file -- better weather and better roads. These factors might also result in higher impact speeds and thus, more severe injury. However, when the expected effects of these factors are coupled with the off-setting effects of the LBSS file having only approximately 88 percent towaways and motorcycles being excluded, it is difficult to conclude that this combination of factors would be sufficient to essentially double the fatality proportion. Thus, it appears that the difference in severity may be due to the selection of the LBSS sample of crashes for investigations. The emphasis on fatal crashes in some NASS procedures may have biased this file to a certain extent. In short, while much more like a "towaway" file than a total crash file, it appears that the LBSS file may indeed contain a slightly more severe set of guardrail impacts than is the case in the comparison groups of States used here. The analyses that follow are based exclusively on LBSS data and are comparative in nature, such that representativeness is much less of a concern.

ANALYSIS AND RESULTS

The following section presents the methods and results of the analyses conducted. Again, the major questions being explored were: (1) the comparative injury-related (i.e., injury severity to drivers) and vehicle trajectory-related (i.e, redirected, snagged, vaulted) performance of different types of barriers and different types of barrier end treatments, and (2) the comparison of performance for LON vs. ends. Data pertaining to the exposure of vehicles to barriers and ends were unavailable for analysis, as well as low severity impacts (driveaways) where no crash data was reported to police or other investigating units. The analyses thus compared various barrier and end types to each other.

LON Analysis

Comparisons of Barrier Types Within LON. Based on data available in the LBSS file, nine types of guardrails (GR) and median barriers (MB) were grouped for analyses. These types are listed in figure 9. Note that GR-9, W-beam strong post, was examined as a separate category and not merged with the other strong post types in GR-2. It was felt that there was some inconsistency in the coding of this barrier type and much of the data referred to an older type of guardrail system likely to be located on lower-volume and lower-speed roadways, and that is no longer being installed.

Distributions of severity of injuries to drivers involved in crashes into the LON of these barriers are shown in tables 8 and 9 in terms of the KABCO and MAIS injury severity scales, respectively. These tables are based on all barrier hits, not just clean hits. The right most column of table 8 also gives the percentage of A or K injuries for each barrier type, and at the bottom of this column are the results of a significance test comparing these A or K percentages. In table 9, the last three columns show percentages having MAIS ≥ 1, MAIS ≥ 2, and MAIS ≥ 3, respectively (representing any injury, moderate to severe injury, and fairly severe injury), with significance test results given at the bottom of the columns. Note that no X^2 is shown for MAIS ≥ 3 since the data were too sparse for the test to be valid. As shown, the severe (A or K) KABCO injury differences across barrier types were marginally significant (p = .055), but the MAIS ≥ 3 injury differences were based on too little data to make valid comparisons. Since there were relatively few injuries at MAIS level 2,

Barrier Type	LBSS Description
GR-1 (weak post)	G1, G2, G3
GR-2 (strong post)	G4 (1W), G4 (2W), G4 (1S), G4 (2S), G9
GR-3 (rigid)	Concrete safety shape
GR-4 (other)	Other guardrail type
GR-9 (W-beam strong post)	W-beam (strong post)
MB-5 (weak post)	MB1, MB2, MB3
MB-6 (strong post)	MB4W, MB4S, MB9
MB-7 (rigid)	Concrete median barrier (MB5)
MB-8 (other)	MB7, other median barrier type

Figure 9. Guardrail and median barrier groups.

differences in the percent with MAIS ≥ 2 were also only marginally significant ($p = .10$). On the other hand, the MAIS ≥ 1 differences were highly significant ($p = .000$).

Although the KABCO results look a bit worse, tables 8 and 9 show that relatively few serious (or fatal) injuries resulted from hits into the LON for any of the barrier types. Thus, if differences in injury severity distributions between barrier types exist, they seem to be occurring primarily at the lower end of the severity scale. This is confirmed by the statistical tests associated with the MAIS data in the last two columns of table 9.

Table 10 is similar to table 9, with the restriction that the data are limited to clean hits into the barriers. Again, the significance test associated with the last two columns of table 10 show significant differences across the barrier types with respect to driver injury vs. no injury, but nonsignificant differences for MAIS ≥ 2. Both tables 9 and 10 suggest higher injury rates associated with barrier types GR-3 (rigid guardrail), MB6 (strong post median barrier), and MB7 (concrete median barrier). All subsequent barrier type comparisons were

Table 8. Distribution of driver injury severity (KABCO) by barrier type: all LON hits.

	KABCO Injury Severity						
Type	0	C	B	A	K	Total	Percent A or K
GR-1	35 (66.0%)	8 (15.1%)	10 (18.9%)	0 (0.0%)	0 (0.0%)	53	0.0%
GR-2	72 (50.0)	13 (9.0)	36 (25.0)	20 (13.9)	3 (2.1)	144	16.0
GR-3	4 (28.6)	1 (7.1)	8 (57.1)	1 (7.1)	0 (0.0)	14	7.14
GR-4	49 (61.3)	10 (12.5)	15 (18.8)	6 (7.5)	0 (0.0)	80	7.5
GR-9	25 (52.1)	6 (12.5)	10 (20.8)	6 (12.5)	1 (2.1)	48	14.6
MB-5	23 (67.7)	3 (8.8)	5 (14.7)	3 (8.8)	0 (0.0)	34	8.8
MB-6	16 (40.0)	6 (15.0)	11 (27.5)	6 (15.0)	1 (2.5)	40	17.5
MB-7	55 (38.7)	17 (11.9)	47 (33.1)	20 (14.8)	3 (2.1)	142	16.2
MB-8	12 (46.2)	4 (15.4)	7 (26.9)	3 (11.5)	0 (0.0)	26	11.5
Total	291 (50.1)	68 (11.7)	149 (25.6)	65 (11.2)	8 (1.4)	581	$X^2_8 = 15.2$ $p = .055$

Table 9. Distribution of driver injury severity (MAIS) by barrier type: all LON hits.

	MAIS Injury Severity								Percent Injured		
Type	0	1	2	3	4	5	6	Total	MAIS ≥ 1	MAIS ≥ 2	MAIS ≥ 3
GR-1	27 (50.0%)	4 (44.4%)	2 (3.7%)	1 (1.9%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	34	50.0%	5.6%	1.9%
GR-2	50 (37.8)	62 (47.0)	13 (9.9)	4 (3.0)	0 (0.0)	1 (0.8)	2 (1.5)	132	62.1	15.2	5.3
GR-3	3 (21.4)	8 (57.1)	3 (21.4)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	14	78.6	21.4	0.0
GR-4	40 (49.4)	33 (40.7)	5 (6.2)	3 (3.7)	0 (0.0)	0 (0.0)	0 (0.0)	81	50.6	9.9	3.7
GR-9	22 (47.8)	18 (39.1)	3 (6.5)	2 (4.4)	0 (0.0)	0 (0.0)	1 (2.2)	46	52.2	13.0	6.5
MB-5	21 (61.8)	12 (35.3)	0 (0.0)	1 (2.9)	0 (0.0)	0 (0.0)	0 (0.0)	34	38.2	2.9	2.9
MB-6	10 (25.6)	21 (53.9)	5 (12.8)	2 (5.1)	0 (0.0)	0 (0.0)	1 (2.6)	39	74.4	20.5	7.7
MB-7	36 (25.9)	80 (57.6)	16 (11.5)	4 (2.9)	1 (0.7)	0 (0.0)	2 (1.4)	139	74.1	16.6	5.4
MB-8	9 (34.6)	16 (61.5)	1 (3.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	26	65.4	3.9	0.0
Total	218 (40.0)	254 (46.6)	48 (8.8)	17 (3.1)	1 (0.2)	1 (0.2)	6 (1.1)	545	X^2_8=30.5 p = .000	X^2_8=13.3 p = .102	--

Table 10. Distribution of driver injury severity (MAIS) by barrier type: clean LON hits.

	MAIS Injury Severity								Percent Injured (MAIS ≥ 1)	Percent Injured (MAIS ≥ 2)
Type	0	1	2	3	4	5	6	Total		
GR-1	23 (56.1%)	16 (39.0%)	1 (2.4%)	1 (2.4%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	41	43.9%	4.9%
GR-2	37 (45.1)	38 (46.3)	6 (7.3)	1 (1.2)	0 (0.0)	0 (0.0)	0 (0.0)	82	54.9	8.5
GR-3	2 (16.7)	8 (66.7)	2 (16.7)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	12	83.3	16.7
GR-4	32 (58.2)	19 (34.6)	2 (3.6)	2 (3.6)	0 (0.0)	0 (0.0)	0 (0.0)	55	41.8	7.3
GR-9	13 (46.4)	13 (46.4)	2 (7.1)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	28	53.6	7.1
MB-5	18 (62.1)	10 (34.5)	0 (0.0)	1 (3.5)	0 (0.0)	0 (0.0)	0 (0.0)	29	37.9	3.5
MB-6	9 (29.0)	17 (54.8)	4 (12.9)	1 (3.2)	0 (0.0)	0 (0.0)	0 (0.0)	31	71.0	16.1
MB-7	35 (28.2)	70 (56.6)	14 (11.3)	3 (2.4)	1 (0.8)	0 (0.0)	1 (0.8)	124	71.8	15.3
MB-8	8 (38.1)	13 (61.9)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	21	61.9	0.0
Total	177 (41.8)	204 (48.2)	31 (7.3)	9 (2.1)	1 (0.2)	0 (0.0)	1 (0.2)	423	X^2_8= 29.71 p = .000	X^2_8= 11.19 p = .191

based on injury (MAIS $\geq$ 1) vs. no injury (MAIS = 0) for drivers using MAIS. This was because the MAIS data were obtained from medical records and were considered more reliable than the police codes. A limitation was that the MAIS data were not as complete. Rows 1 through 5 (guardrails) and rows 6 through 9 (median barriers) of tables 9 and 10 were also analyzed separately as subtables relative to MAIS $\geq$ 1. For all hits, the respective X^2-statistics and p-values were $X^2_4 = 6.762$ (p = .149) for guardrails and $X^2_3 = 14.874$ (p = .002) for median barriers; for clean hits these quantities were $X^2_4 = 9.975$ (p = .041), and $X^2_3 = 10.298$ (p = .016). Thus, when considered separately, the differences in injury rates across the different types of median barriers were statistically significant, while the injury rate differences across guardrail types were only marginally significant. Since injury rates for guardrails and median barriers were relatively similar, it seemed most efficient to analyze guardrails and barriers together rather than to split up a moderately sized data set into two rather small subsets.

In order to further investigate barrier type differences while taking into account the effects of certain covariates, logistic models of the form

$$\mathrm{lo} \frac{p}{1-p} = \beta_o + \sum_{j=1}^{J} \beta_j X_j \tag{6}$$

were fit to the data using SAS PROC LOGISTIC.[8] The quantity R = (p/1-p) in equation 6 can be thought of as the risk of injury. Taking exponentials of both sides of equation 6 shows that injury risk, R, can be expressed as the product of factors:

$$R = (e^{\beta_o})(e^{\beta_1 X_1})(e^{\beta_2 X_2})...(e^{\beta_J X_J}) \tag{7}$$

A model of this type formulated to make comparisons among the five guardrail and four median barrier types contained eight dummy or indicator variables to flag the various guardrail and barrier types. More specifically, these variables were,

X_1 = 1 if GR-2, 0 otherwise.

X_2 = 1 if GR-3, 0 otherwise.

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.

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X_8 = 1 if MB-8, 0 otherwise.

The model also contained three covariates: impact speed, vehicle curb weight, and impact angle. Thus, the estimated model coefficients provide estimates of the relative injury risk associated with the different barrier types while taking into account the fact that the different types of barriers may have been struck by vehicles of different sizes with different speeds and impact angles. Ranges of the variation in these factors are given in the introductory section.

Other variables that were tested as covariates, but were found not to make a statistically significant improvement in the model, were yaw angle, effective barrier height, separation angle, horizontal distance to barrier, length of barrier, and driver age. For a vehicle striking guardrail type GR-1, all of the variables $X_1 = X_2 = \ldots = X_8 = 0$, so the estimated injury risk has the form,

$$R_1 = (e^{\beta_o})\ (\textit{covariate effects}) \tag{8}$$

For a vehicle striking guardrail type GR-2, the dummy variable $X_1 = 1$ and all other dummy variables are zero, so the injury risk has the form:

$$R_2 = (e^{\beta_o})(e^{\beta_1})(\textit{covariate effects}) \tag{9}$$

For fixed values of the covariates then

$$R_2 = (e^{\beta_1})\ R_1 \tag{10}$$

Thus, the estimated model coefficients $\beta_1, \ldots, \beta_8$ give multiplication factors for injury risks of GR-2, ..., MB-8 relative to GR-1. Table 11 lists the estimated values of the β's when the model was fit to the all hits data. The table also gives standard errors and p-values for the estimated parameters. Since barrier types GR-2 through MB-8 are compared in this model with barrier type GR-1, the statistical significance of the estimates $B_1, \ldots, B_8$ is a function of the variability in injury severity associated with hits into barrier type 1, and with each of the other types in turn. Thus, the variability (or inversely, the stability) of the behavior of barrier type 1 is a factor relative to the statistical significance of each of the other barrier effect estimates. The estimate of β_1 is statistically significant and has the value $\beta_1 = .84$. Thus, for equal speed, curb weight, and impact angle, the injury risk for a crash into guardrail type GR-2 is estimated to be $(e^{.84}) = 2.32$ times the injury risk of a crash into a guardrail of type GR-1.

Guardrail type 1, weak post systems, served as a reference group or baseline for the model of table 11. Thus, each other barrier type is compared to weak post systems, a design which provides a more forgiving impact by allowing large deflection. These systems should be limited to locations where such large deflections are permissible. A disadvantage is generally extensive barrier damage in a crash. The fact that all of the estimates are positive indicates that the estimated injury risk was higher for each of the other barrier types than for weak post systems. However, the standard error and p-values show some of these differences to be not statistically significant (i.e., GR-4, "other" guardrail; GR-9, W-beam strong post guardrail; and MB-5, weak post median barrier).

Table 11. Logistic model results comparing nine barrier types: all LON hits.

Variable	Parameter Estimate	Standard Error	p-value
GR-2	.84	.40	.03
GR-3	1.53	.88	.08
GR-4	.57	.44	.19
GR-9	.35	.50	.48
MB-5	.19	.54	.72
MB-6	1.25	.53	.018
MB-7	1.76	.46	.0002
MB-8	.92	.61	.127
Speed	.05	.01	.0001
Curb Weight	-.05	.01	.0013
Impact Angle	.02	.007	.001

In order to further examine differences in barrier types, some grouping of similar barriers was done. This resulted in six groups of barriers as follows:

Group 1 - GR-1, MB-5 (Weak post guardrail and median barrier)
Group 2 - GR-2 (Strong post guardrail)
Group 3 - MB-6 (Strong post median barrier)
Group 4 - GR-3 (Shaped concrete guardrail)
Group 5 - MB-7 (Shaped concrete median barrier)
Group 6 - GR-4, MB-8, GR-9 (Other guardrail and median barrier)

Table 12 shows results from a logistic model similar to that of table 8, but based on the six groups of barriers. From the p-values shown in the top portion of the table, it can be seen that groups 2, 3, and 5 all differ significantly from group 1; group 6 does not differ significantly from group 1; and that the significance of group 4 is marginal. The positive signs of the coefficients indicate that groups 2 through 6 are estimated to be associated with injury risks greater than that of group 1. By estimating other models with groups 2 through 6 omitted one at a time, the table of pairwise comparisons shown in the middle portion of table 12 was generated. This table shows, for example, group 2 to differ significantly from groups 1 and 5, but not from groups 3, 4, and 6. The bottom portion of the table lists the relative risks of injury for each significant difference.

The format of table 13 is the same as that of table 12. Here the models were fit to the clean hits data subfile. The results are quite similar.

Table 12. Logistic model comparing six groups of barrier types: all LON hits.

Variable	Estimate	Standard Error	p-Value
Group 2 (strong post GR)	.77	.34	.022
Group 3 (strong post MB)	1.18	.49	.016
Group 4 (rigid GR)	1.46	.85	.087
Group 5 (rigid (MB)	1.69	.42	.001
Group 6 (other GR and MB)	.49	.33	.138
Speed	.05	.01	.001
Curb Weight	-.05	.01	.001
Impact Angle	.02	.007	.001

Pairwise comparisons: p-values

			Group		
Group	2	3	4	5	6
1	.02	.02	.09	.001	ns
2		ns	ns	.02	ns
3			ns	ns	ns
4				ns	ns
5					.002

Relative risks for significant differences:

$R_2/R_1 = 2.17$ $R_5/R_2 = 2.49$

$R_3/R_1 = 3.27$

$R_4/R_1 = 4.31$ $R_5/R_6 = 3.30$

$R_5/R_1 = 5.40$

ns = not significant

Table 13. Logistic model comparing six groups of barrier types: clean LON hits.

Variable	Estimate	Standard Error	p-Value
Group 2 (strong post GR)	.55	.40	.169
Group 3 (strong post MB)	1.07	.54	.049
Group 4 (rigid GR)	2.15	1.11	.055
Group 5 (rigid MB)	1.69	.45	.001
Group 6 (other GR and MB)	.55	.38	.155
Speed	.05	.01	.001
Curb Weight	-.05	.02	.001
Impact Angle	.03	.01	.001

Pairwise comparisons: p-values

	Group				
Group	2	3	4	5	6
1	ns	.05	.06	.001	ns
2		ns	ns	.008	ns
3			ns	ns	ns
4				ns	ns
5					.005

<u>Relative risks for significant differences:</u>

$R_3/R_1 = 2.92$ $R_5/R_2 = 3.11$
$R_4/R_1 = 8.55$
$R_5/R_1 = 5.41$ $R_5/R_6 = 3.13$

ns = not significant

Barrier Performance in Terms of Vehicle-Barrier Interaction and Post-Impact Trajectory. While the above analysis involved performance in terms of harm to the driver, additional analyses were conducted to examine differences in vehicle-barrier interaction and vehicle trajectory following impact. All of the analyses in this section was limited to vehicle hits into barrier LON only. In many cases, separate analyses are carried out for all barrier hits and clean hits only. Table 14 is a tabulation of barrier performance by barrier type. This table shows that 75 percent of the case vehicles were redirected by the barrier, 8.5 percent snagged, 9 percent overrode the barrier, and 3 percent or less each vaulted, penetrated, or had some other involvement with the barrier. Guardrail type GR-1, weak post systems, had the highest percent of snags (23 percent), but some snagging is expected for this more forgiving design. Type GR-4 also had a high snag percentage (18 percent) and the highest percentage of overrides (21 percent). Type GR-9, W-beam strong post, had a high percentage of overrides (16 percent) and the highest percentage vaulting the barrier (12 percent).

Table 14. Vehicle-barrier interaction by barrier type: all LON hits.

	Performance						
Barrier Type	Redirected	Snagged	Overrode	Vaulted	Penetrated	Other	Total
GR-1	34 (60.7%)	13 (23.2%)	4 (7.1%)	0 (0.0%)	2 (3.6%)	3 (5.4%)	56
GR-2	112 (75.7)	10 (6.8)	10 (6.8)	6 (4.1)	7 (4.7)	3 (2.0)	148
GR-3	13 (86.7)	0 (0.0)	2 (13.3)	0 (0.0)	0 (0.0)	0 (0.0)	15
GR-4	43 (50.6)	15 (17.7)	18 (21.2)	0 (0.0)	4 (4.7)	5 (5.9)	85
GR-9	29 (59.2)	5 (10.2)	8 (16.3)	6 (12.2)	1 (2.0)	0 (0.0)	49
MB-5	28 (82.4)	4 (11.8)	1 (2.9)	0 (0.0)	0 (0.0)	1 (2.9)	34
MB-6	36 (87.8)	2 (4.9)	1 (2.4)	1 (2.4)	0 (0.0)	1 (2.4)	41
MB-7	135 (91.2)	0 (0.0)	8 (5.4)	0 (0.0)	0 (0.0)	5 (3.4)	148
MB-8	21 (77.8)	2 (7.4)	2 (7.4)	1 (3.7)	1 (3.7)	0 (0.0)	27
Total	451 (74.9)	51 (8.5)	54 (9.0)	13 (2.2)	15 (2.5)	18 (3.0)	603

A tabulation of barrier performance by driver injury (injured vs. not injured based on MAIS) is presented in table 15. Injury rates vary relatively little across the performance categories as is confirmed by the nonsignificant X^2-statistic. Logistic models were run to further investigate relationships between barrier performance and driver injury while taking impact speed, curb weight, and impact angle into account. In these analyses, the injury risk to drivers of vehicles that were snagged, which overrode the barrier, or which fell into any of the remaining three performance categories were compared to the injury risk of drivers whose vehicles were redirected by the barrier. Results from two such analyses are shown in tables 16 and 17. In table 16, which shows results from a model fit to data from all barrier hits, none of the barrier performance indicator variables was statistically significant (compared to redirected), nor were there statistically significant differences between the performance estimates, as can be seen from an examination of their standard errors. In other words, for any driver injury vs. no injury, categories like snagging, overriding, etc. are not statistically different from redirection. Due to small sample sizes, the categories of vaulted, penetrated, and other were combined for the modeling.

Table 15. Distribution of barrier performance by driver injury (MAIS): all LON hits.

Performance	Injured (MAIS $\geq$ 1)	Not Injured	Total
Redirected	258 (61.4%)	162 (38.6%)	420
Snagged	30 (61.2)	19 (38.8)	49
Overrode	31 (59.6)	21 (40.4)	52
Vaulted	12 (85.7)	2 (14.3)	14
Penetrated	5 (41.7)	7 (58.3)	12
Other	11 (61.1)	7 (38.9)	18
Total	347 (61.4)	218 (38.9)	565

X^2_4 df = 5.536 p = .354

Table 16. Logistic model results for injury risk as function of barrier performance: all LON hits.

Variable	Estimate	S.E.	p-Value
Snagged	.34	.37	.36
Overrode	.02	.40	.95
Vaulted, Penetrated, Other	-.55	.46	.24
Speed	.05	.009	.0001
Curb Weight	-.05	.01	.0005
Impact Angle	.02	.007	.0017

Table 17 shows results from the same model fit to the clean hits data. The results are similar to table 16.

Table 17. Logistic model results for injury risk as a function of barrier performance: clean hits only.

Variable	Parameter Estimate	S.E.	p-Value
Snagged	.63	.43	.141
Overrode	-.19	.51	.713
Vaulted, Penetrated, Other	-.27	.58	.640
Speed	.04	.01	.0001
Curb Weight	-.05	.02	.0011
Impact Angle	.03	.009	.0018

These injury results are not what would normally be expected. In particular, vaulting and penetrating a barrier are considered barrier failures and more likely to produce injury than redirection. Table 15 showed vaulting to produce injury 86 percent of the time, but penetration produced injury only 42 percent of the time. Thus, combining these two outcomes with the category of "other" may partially account for the modeling results, which indicate no difference in these failure modes and redirection.

Further exploration through three-way cross tabulations showed a few possible coding errors by investigators, in that eight of the vehicles indicated to have either overrode, vaulted, or penetrated a barrier also were coded to have returned to the roadway or crossed to the other side. Injury to drivers of vehicles which overrode, vaulted, or penetrated was present over 80 percent of the time when the vehicle either struck another object or rolled over.

Examination of a number of variables for each case of vaulting and penetrating a barrier also helped in understanding some of the injury results. For the vaulting cases, almost all involved W-beam barriers, with about half being the older W-beam strong post design. Many of the barrier heights were less than 28 in (711 mm) in height, and several had curbs present. Almost half of the impact angles exceeded 28 degrees. Only one case had an impact speed in the 46 to 55 mi/h (74 to 89 km/h) range, but four others were not coded, perhaps implying high speeds. Six of the cases involved rollover. Most of the crashes occurred on Interstate routes, with only two on county routes.

For the penetrating cases, about half involved cable guardrail, which is a forgiving system that allows large deflections. Most of the barrier heights were less than 28 in (711 mm), and only a few curbs were present. About half of the impact angles exceeded 28 degrees. Two of the impact speeds exceeded 60 mi/h (97 km/h) and eight more were not coded, perhaps implying high speeds. Most of the cases involved no subsequent impacts, and there was only one rollover. About half of the crashes occurred on local or county routes, and only three involved large trucks.

Post-Impact Vehicle Trajectory Following First Barrier Impact. Table 18 gives a tabulation of post-impact trajectory by barrier type. Only the clean hits data were used in this tabulation since the trajectory variable seemed most relevant to the clean hits. Most vehicles either remained on the roadside or were returned to the roadway. Weak post (GR-1) guardrails returned a much lower percentage of vehicles to the roadway than did any other barrier type, but some snagging is expected with this design.

Table 19 gives the distribution of driver injury by trajectory and shows injury rates for trajectories where the vehicle returns to or crosses the roadway to be higher than those remaining on the roadside and remaining on top of, or going over or through the barrier. (It is again noted here that since multiple vehicle accidents were eliminated from the file, those vehicles returning to or crossing the roadway did not strike another vehicle.) These results were partially confirmed by a logistic model fit to the data that contained three dummy variables indicating trajectories of types 2, 3, and 4 below, relative to remaining on the roadside. Cases with trajectories falling into the "other" category were omitted from this analysis. From the model (table 20), the trajectory of being "returned to the roadway" is estimated to have a significantly higher risk of injury compared to "remaining on the roadside," while those of "crossing the roadway and off the opposite side," and "on top of or through," do not.

Table 18. Distribution of post-impact trajectory by barrier type: clean hits into LON.

	Trajectory Following First Impact					
Barrier Type	Remained on Roadside	Returned to Roadway	Crossed Roadway Off Opp. Side	On Top of, Over, Through Barrier	Other	Total
GR-1	28 (68.29%)	2 (4.88%)	4 (9.76%)	6 (14.63%)	1 (2.44%)	41
GR-2	40 (44.44)	27 (30.00)	6 (6.67)	14 (15.56)	3 (3.33)	90
GR-3	7 (53.85)	6 (46.15)	0 (0.00)	0 (0.00)	0 (0.00)	13
GR-4	26 (45.61)	13 (22.81)	3 (5.26)	15 (26.32)	0 (0.00)	57
GR-9	14 (45.16)	9 (29.03)	1 (3.23)	7 (22.58)	0 (0.00)	31
MB-5	18 (62.07)	9 (31.03)	1 (3.45)	1 (3.45)	0 (0.00)	29
MB-6	15 (45.45)	13 (39.39)	2 (6.06)	2 (6.06)	1 (3.03)	33
MB-7	69 (52.27)	42 (31.82)	16 (12.12)	4 (3.03)	1 (0.76)	132
MB-8	13 (61.90)	6 (28.57)	0 (0.00)	2 (9.52)	0 (0.00)	21
Total	230 (51.45)	127 (28.41)	33 (7.38)	51 (11.41)	6 (1.34)	447

Table 19. Distribution of post-impact trajectory by driver injury: clean hits.

Trajectory	Injured (MAIS > 1)	Not Injured	Total
Remained on roadside	116 (53.2%)	102 (46.8%)	218
Returned to roadway	83 (68.6)	38 (31.4)	121
Crossed roadway off opposite side	22 (68.75)	10 (31.25)	32
Remained on top of, ran through, went over barrier	21 (43.75)	27 (56.25)	48
Total	242 (57.75)	177 (42.25)	419

$X^2_3 = 13.12$ $p = .004$

In comparing the differences between the results of tables 19 and 20, note that the logistic model, in addition to taking into account the effects of impact speed and angle and curb weight, also restricts the usable data to cases for which an estimated impact speed was available. Thus, while 425 observations were included in table 19, only 294 were used in the logistic model of table 20.

Table 20. Logistic model results for injury risk as a function of post-impact trajectory: clean hits.

Variable	Estimate	S.E.	p-Value
Returned to roadway	.69	.31	.024
Crossed roadway	.14	.49	.770
On top of, through, over	-.13	.44	.772
Speed	.04	.01	.0002
Curb Weight	-.06	.02	.0002
Impact Angle	.03	.009	.0006

Subsequent Impact Following First Barrier Impact. Frequencies of subsequent impacts with certain other objects are shown in table 21 by barrier type. "All hits" data were used for these analyses since "clean hits" subsequent impacts were restricted to the same longitudinal barrier. No subsequent impacts with other vehicles are shown in table 21 since these cases were excluded from all the data files for this analysis. Approximately 9 percent of the vehicles rolled over after striking the barriers. The rollover rate for barrier type MB-7, the concrete median barrier, is nearly double this overall rate. (The rollover rate for GR-3 was also quite large, 20 percent, but was based on only 15 cases.)

Table 21. Distribution of subsequent impact following first barrier impact by barrier type: all LON hits.

	Subsequent Impact					
Barrier Type	None	Other Roadside Object	Same Barrier	Other Barrier	Rollover	Total
GR-1	35 (67.3%)	8 (15.4%)	6 (11.5%)	3 (5.8%)	0 (0.0%)	52
GR-2	67 (48.2)	26 (18.7)	20 (14.4)	14 (10.1)	12 (8.6)	139
GR-3	6 (40.00)	1 (6.67)	5 (33.33)	0 (0.00)	3 (20.0)	15
GR-4	47 (55.3)	20 (23.5)	8 (9.4)	6 (7.1)	4 (4.7)	85
GR-9	25 (55.6)	9 (20.0)	4 (8.9)	3 (6.7)	4 (8.9)	45
MB-5	22 (64.7)	2 (5.9)	7 (20.6)	2 (5.9)	1 (2.9)	34
MB-6	25 (62.5)	4 (10.0)	6 (15.0)	2 (5.0)	3 (7.5)	40
MB-7	72 (49.7)	2 (1.4)	45 (31.0)	3 (2.1)	23 (15.9)	145
MB-8	16 (61.5)	2 (7.7)	6 (23.1)	1 (3.9)	1 (3.9)	26
Total	315 (54.2)	74 (12.2)	107 (18.4)	34 (5.9)	51 (8.8)	581

Table 22. Distribution of subsequent impact by driver injury: all hits.

Subsequent Impact	Injured (MAIS ≥ 1)	Not Injured	Total
None	164 (55.4%)	132 (44.6%)	296
Other roadside object	47 (68.1)	22 (31.9)	69
Same barrier	58 (58.6)	41 (41.4)	99
Another barrier	20 (64.5)	11 (35.5)	31
Rollover	43 (87.8)	6 (12.2)	49
Total	332 (61.0)	212 (39.0)	544

$X^2_4 = 20.51$ $p = .001$

Injury distributions associated with subsequent impacts are shown in table 22, which shows rollover to have the highest rate of driver injury. However, in a logistic model, which compared the injury risk of rollover with that for all other subsequent impacts (including none), the estimated rollover effect was not statistically significant ($p = .119$). Rollovers, in general, are investigated further in the last section.

End Treatment Analyses

Comparison of End Treatments. Tables 23 and 24 display the maximum data in the file on type of end treatment cross-classified by driver injury severity. In these tables, end treatment type and LON are determined by the barrier subset variable called "end treatment type" for the first impact. The data are not restricted to clean hits. Following some initial analyses comparing injured vs. non-injured drivers, it seemed that differences between types of barrier-ends and ends vs. LON were more pronounced in the more serious injuries rather than in the "any injury" vs. "no injury" comparison. This can be seen in the last columns of the tables, which show percents with A or K injuries and percents with MAIS ≥ 3, respectively. It can also be seen from the tables that blunt and turndown were the predominant end treatment types present in the data. In most of the analyses that follow, all of the remaining end treatment types were combined into a single "other" category. This collapsing seems reasonably justified in terms of the serious injury percentages of tables 23 and 24. A problem that arose in the analysis of end treatment types was that while impact speed has been shown to be a significant factor relative to driver injury, estimated impact speed was present for only about 27 percent of the end hit cases when these analyses were conducted. Neither curb weight nor impact angle were found to have a significant effect.

Table 23. Distribution of end treatment by driver injury (KABCO): all barrier hits.

	Injury Severity						
End Treatment Type	No Injury	C	B	A	K	Total	Percent A or K
Length of Need	294 (50.4%)	68 (11.7%)	149 (25.6%)	64 (11.0%)	8 (1.37%)	583	12.4
Blunt	60 (44.8)	18 (13.4)	31 (23.1)	22 (16.4)	3 (2.2)	134	18.7
Non-Breakaway Cable	10 (41.7)	2 (8.3)	6 (25.0)	6 (25.0)	0 (0.0)	24	25.0
Turndown	51 (47.2)	10 (9.3)	26 (24.1)	16 (14.8)	5 (4.6)	108	19.4
Breakaway Cable	14 (41.2)	2 (5.9)	10 (29.4)	8 (23.5)	0 (0.0)	34	23.5
Anchoring to Backslope	6 (46.15)	3 (23.08)	3 (23.08)	1 (7.69)	0 (0.00)	13	7.7
Attached to Parapet	5 (22.73)	3 (13.64)	9 (40.91)	5 (22.73)	0 (0.00)	22	22.7
Other	3 (37.50)	0 (0.00)	1 (12.50)	4 (50.00)	0 (0.00)	8	50.0
Total	443 (47.8)	106 (11.5)	235 (25.4)	126 (13.6)	16 (2.2)	926	15.3

Table 24. Distribution of end treatment type by driver injury (MAIS): all hits into barrier.

		Driver Injury Severity (MAIS)							
End Treatment Type	0	1	2	3	4	5	6	Total	Percent MAIS ≥ 3
Length of Need	221 (38.8%)	274 (48.1%)	48 (8.4%)	18 (3.2%)	1 (0.18%)	1 (0.18%)	6 (1.1%)	569	4.7
Blunt	52 (40.9)	51 (40.2)	11 (8.7)	5 (3.9)	3 (2.4)	4 (3.2)	1 (0.8)	127	10.3
Non-Breakaway Cable	9 (40.9)	8 (36.4)	2 (9.1)	2 (9.1)	1 (4.6)	0 (0.0)	0 (0.0	22	13.6
Turndown	37 (36.6)	43 (42.6)	11 (10.9)	5 (5.0)	0 (0.0)	0 (0.0)	5 (5.0)	101	10.0
Breakaway Cable	9 (27.3)	15 (45.5)	5 (15.2)	3 (9.1)	1 (3.0)	0 (0.0)	0 (0.0)	33	12.1
Anchoring to Backslope	6 (46.15)	5 (38.46)	1 (7.69)	1 (7.69)	0 (0.0)	0 (0.0)	0 (0.0)	13	7.7
Attached to Parapet	5 (26.32)	10 (52.63)	4 (21.05)	0 (0.00)	0 (0.0)	0 (0.0)	0 (0.0)	19	0.0
Other	2 (25.00)	3 (37.50)	1 (12.50)	1 (12.50)	1 (12.50)	0 (0.0)	0 (0.0)	8	25.0
Total	341 (38.2)	409 (45.9)	83 (9.3)	35 (3.9)	7 (0.8)	5 (0.6)	12 (1.4)	892	6.7

Table 25 shows results from a logistic model for comparing three types of end hits with LON hits, using impact speed as a covariate.

Table 25. Logistic model results for comparing three end types vs. LON relative to risk of injury at MAIS $\geq$ 3: all hits.

Variable	Estimate	Standard Error	p-value
Blunt ends	1.78	.71	.012
Turndown ends	1.42	.70	.041
Other end types	.96	.71	.174
Speed	.03	.02	.027

This model shows estimated risk of serious injury (MAIS $\geq$ 3) to be significantly greater for blunt ends and turndown ends than for LON. Estimated injury risk for the combined other end types are not significantly greater than that for LON; however, the standard errors shown in table 25 suggest that the injury risks do not differ significantly across the three end types either.

Comparisons of the three end types are further explored in table 26 which shows injury severity classified by the three end types for two more restrictive types of end hits. In the upper portion of the table only upstream, end-on hits (from the all hits file) are considered. Upstream hits within 25 ft (7.62 m) of the end are tabulated in the lower portion of the table. In neither case are there significant differences between end types.

Further Analysis of Rollovers

Vehicle rollovers associated with barrier impacts were further studied by examining associations between rollovers and driver injury severity and between rollovers and barrier end hits vs. LON. In particular, these analyses address the question of whether or not the higher injury risk associated with end hits is primarily a result of more rollovers associated with end hits. The analyses that follow were based on clean hits data. Table 27 shows results from contingency tables of rollover vs. the three characterizations of driver injury used in previous analyses. All three characterizations show significantly higher injury or serious injury rates associated with rollovers.

Table 26. Comparisons of end types for restricted end hits.

a) End-on upstream hits

	MAIS		
End Type	≥ 3	< 3	Total
Blunt	7 (11.9%)	52 (88.1%)	59
Turndown	4 (13.8)	25 (86.2)	29
All Other	5 (16.7)	25 (83.3)	30
Total	16 (13.6)	102 (86.4)	118

$X^2_2 = .393$ $p = .822$

b) Upstream hits, end-on to 25 ft (7.62 m)

	MAIS		
End Type	≥ 3	< 3	Total
Blunt	9 (11.1%)	72 (88.9%)	81
Turndown	7 (10.6)	59 (89.4)	66
All Other	7 (13.5)	45 (86.5)	52
Total	23 (11.6)	176 (88.4)	199

$X^2_2 = .259$ $p = .879$

Note: Numbers represent total cases.
( ) represent associated percentages.

Table 27. Rollover vs. driver injury: clean hits only.

	Percent Injured		
Rollover Status	MAIS ≥ 1	MAIS ≥ 3	A+K
No Rollover	59.4%	5.8%	13.5%
Rollover	84.7%	15.2%	30.2%
X^2_1d.f.	20.9	11.2	18.6
p-value	.000	.001	.000

Comparisons of rollover rates for hits into length of need with rollover rates for end hits yielded the following rates:

- 8.46% for LON.
- 13.62% for all end hits.
- 17.16% for upstream, end-on hits.
- 17.43% for upstream hits within 25 ft (7.62 m) of end.

All three end rates differed significantly from the LON rate with $p < .02$ in each comparison. Tables 28 and 29 show three-way breakdowns of rollover by end/LON by injury severity (MAIS and KABCO respectively), where end hits refer to any end hit. These tables show no significant differences in injury rates between ends and LON when rollovers occurred, but when no rollovers occurred, significantly higher injury rates were associated with end hits. Similar tables were analyzed for comparing LON hits with upstream end-on hits and upstream hits within 25 ft (7.62 m) of end. The results were the same; no significant differences when rollovers occurred, and higher injury rates associated with end hits when rollovers did not occur. Thus, it seems that end hits are more likely to result in serious injury than LON hits by:

- Being more likely to produce rollover.
- By producing more serious injuries when no rollovers occur.

Table 28. Three-way table of rollover by end* vs. LON by MAIS injury severity.

	Injury Severity			
Rollover	End/LON	MAIS < 3	MAIS ≥3	Total
Yes	LON	42 (85.7%)	7 (14.3%)	49
	End	30 (83.3)	6 (16.7)	36
	Total	72	13	85
	X^2_1 = .051 p = .763			
No	LON	498 (96.5%)	18 (3.5%)	516
	End	254 (90.4)	27 (9.6)	281
	Total	752	45	797
	X^2_1 = 12.791 p = .000			

* In this table any hit in which an end type was coded was considered an end hit; length-of-need was "no" end hit. Numbers represent total cases and ( ) represent associated percentages.

Table 29. Three-way table of rollover by end* vs. LON by KABCO injury severity.

	Injury Severity			
Rollover	End/LON	O,C,B	A,K	Total
Yes	LON	34 (68.0%)	16 (32.0%)	50
	End	33 (71.7)	13 (28.3)	46
	Total	67	29	96
	X^2_1 = .159 p = .690			
No	LON	474 (89.3%)	57 (10.7%)	531
	End	235 (81.3)	54 (18.7)	289
	Total	709	111	820
	X^2_1 = 10.107 p = .001			

*Same end and LON definition as in table 28.

IV. CLINICAL ANALYSIS OF BARRIER FAILURE MODES

SCOPE

The following accident groups were examined by analyzing the recorded data together with diagrams and scene slides:

- 163 length-of-need cases where the barrier was the first object struck and a barrier failure was suspect.
- 25 breakaway cable terminal (BCT) cases.
- 60 turndown end cases.

The set of cases reviewed in this section was comprised of: (1) all LON impacts where the barrier was the first object struck and the vehicle was not redirected; and (2) all barrier end impacts. The accident cases were viewed with the idea of assessing what happened and which significant factors contributed to the "failure" of the barrier systems. In many cases, "failure" was not an accurate description. These discrepancies are discussed below within each of the three accident group categories.

A larger set of data was analyzed for the two W-beam end treatment types. Selection of these data was based on a barrier being the first object struck. Included in the group are some of the same cases analyzed more in-depth.

LENGTH-OF-NEED CASES

Of the 163 longitudinal barrier cases analyzed, the following were not included in the analysis of this section:

- 11 W-beam guardrail cases with strong posts spaced at 12 ft-6 in (3.81 m) centers.
- 30 old style cable guardrail systems (4 were coded G1).
- 16 miscoded or obviously erroneous data cases.
- 24 nonstandard miscellaneous barrier systems.

Thus, only 82 cases remained to be analyzed further and of these, some had missing data elements. These cases included standard guardrail and median barrier designs as found in the 1977 AASHTO Barrier Guide with one exception. The General Motors concrete safety shape was also included.

In many cases, the barrier did not fail, but unusual impact conditions created a series of events that departed from the standard smooth redirection that occurs in full-scale crash tests. For example, snagging/pocketing was coded for several weak post systems.

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The weak posts do snag a vehicle's wheels, but it is not a failure of the system as the snagging forces are not excessive. Another example is the spinning away from a barrier that occurs with vehicles that are yawing (i.e., not tracking) prior to striking the barrier.

In examining the available information, significant factors were determined to be involved in the accident with respect to barrier performance. Of the 82 cases, the following were determined:

- 40 had a single factor contributing to barrier "failure."
- 36 had 2 significant factors contributing to barrier "failure."
- 6 had 3 significant factors contributing to barrier "failure."

Single significant factors attributed to the lack of smooth redirection and/or containment of the vehicle are described in table 30 under the column heading "none." As shown in the table, over half of the cases in that column included higher impact angles and/or speeds than the current testing criteria specify or had a vehicle yaw angle greater than 10 degrees. The yaw angle is zero for all current crash test conditions.

Table 30 also describes the distribution where two significant factors were judged to contribute to the vehicle/barrier behavior. The two angles again dominated these factors.

Cases with three or more factors are also included in table 30 with footnotes to denote the additional factors. Although the angles again represent the highest numbers, low barrier height, heavy vehicles, and curbs also are represented in nearly as many cases.

Tables 31 and 32 summarize the findings by barrier type. Also included is injury information on the driver (MAIS ≥ 3 or fatal) and the available estimated impact severity value. Other values shown are described at the end of the tables.

Of the 82 barrier cases, the G4 guardrail and the MB5 concrete median barrier (CMB) represented over 60 percent of the total. The various barrier systems are discussed below; guardrail cases are in table 31 and table 32 summarizes the median barrier cases.

Guardrail, G1

Of the four cases for this design, snagging/pocketing was coded on three. Two of the cases were low speed impacts in which the cable system typically captured the vehicle. The case in which the vehicle penetrated the barrier system could only be explained from the yaw angle and/or excessive speed. The case involving the failed lower cable was difficult to explain; however the yaw angle was considered the only obvious factor. No serious injuries resulted.

Table 30. Significant factors contributing to LON standard barrier "failures."

	ψ>10°	T	BL	BH	HV	UV	CRB	CMB	CF	GM	CRV	V>60	LGT	HIS	None	TOTAL
θ >25°	6[A]		1	2		1	1		1		4	1		1	8	26
ψ >10°			1			3		1	1	1		2			8	17
R/O*		1			1	1[C]							1		2	6
BL					1		2									3
BH							1								1	2
HV			1[B]								1				4	6
GM											1[D]	1				2
WP							1								1	2
SNW							1								1	2
V>60							1								6	7
OBJ															3	3
M															2	2
MV															1	1
CMB															1	1
V/B															1	1
θ = ?															1	1
Totals	6	1	3	2	2	5	7	1	2	1	6	4	1	1	40	82

Legend:

θ - impact angle
ψ - yaw angle
R/O* - rollover not barrier induced
BL - low barrier mounting height
BH - high barrier mounting height
HV - heavy vehicle
UV - van, utility vehicle
GM - General Motors safety shape
WP - weak post barrier
SNW - snow accumulation in front of barrier
OBJ - fixed object too close to barrier

T - sloping terrain in front of barrier
CRB - curb in front of barrier
CMB - precast barrier movement
CF - component failure
CRV - curved barrier
V - impact speed, > 60 mi/h (96 km/h)
LGT - barrier too short
HIS - high initial step, MB5SS
AF - anchorage failure
V/B - vehicle/barrier damage incompatible
IS - severity index

M - minor impact
MV - multiple vehicle
CMB - precast barrier moved
[A] - additional factors include
  T - 1 case
  UV - 1 case
  CRB, IS > 96 - 1 case
[B] - add. factors: BL, CRB, R/O
[C] - add. factors: θ & ψ = 0
[D] - add. factors: V, R/O

Table 31. Summary of guardrail cases.

YEAR	PSU	CASE	B33	B66	B68	B31	DRIVER MAIS ≥3	IMPACT SEVERITY	SIGNIFICANT FACTORS
4 CASES G1									
84	78	253W	1	5	0	1	-	>19	V, ψ
85	36	503W	1	2	0	1	-	1>	WP
85	78	551E	1	2	0	1	-	low	M
86	36	504D	1	2	0	1	-	2.2	CF, ψ (lower cable failed)
4 CASES G2									
82	26	176T	2	8	0	2	-	-	U/R, θ, CRV
83	30	517W	2	2	0	2	-	15	ψ
84	30	504V	2	8	0	1	-	57.8	θ
86	33	064D	2	8	0	2	-	-	ψ
5 CASES G3									
82	26	200W	3	2	0	1	-	25	θ, ψ, low speed
83	26	104W	3	2	0	1	-	2.5	M, PAD, low speed
83	26	116W	3	8	0	1	-	39	CRV (stopped), low speed, θ
84	34	501Z	3	8	0	1	-	30	BH, CRB
85	36	510V	3	2	0	1	-	45	CRB, WP
28 CASES G4									
82	2	513W	5	3	0	1	-	1>	SNW
82	2	523W	5	2	0	2	-	113*	θ
82	3	501V	6	2	0	1	-	26	θ, CRB
82	32	508R	6	3	0	1	-	-	BL, HV
82	76	122W	6	2	0	1	-	104	θ, CRV
82	80	510R	4	4	6	1	-	5	ψ, UV
82	81	504W	4	2	2	1	-	28	BH
82	81	508W	4	5	2	1	-	171*	BH

Table 31. Summary of guardrail cases (Continued).

YEAR	PSU	CASE	B33	B66	B68	B31	DRIVER MAIS ≥3	IMPACT SEVERITY	SIGNIFICANT FACTORS
82	81	511W	4	3	0	2	-	-	θ, ψ, T
83	2	043Q	5	1	6	2	-	-	UV, ψ
83	2	507R	5	3	6	1	-	10	ψ, UV
83	8	502V	6	2	0	1	-	129*	θ, ψ, CRB
83	32	051L	6	1	6	2	-	-	HV
83	32	063R	6	3	2	1	-	15	OBJ
83	32	130R	7	5	0	1	-	-	HV, CRV
83	80	517W	5	3	0	3	-	-	BL, θ, ψ
83	81	079P	4	3	0	1	7	13	θ, ψ, UV
84	80	525W	5	1	6	1	-	?	R/O [θ, ψ, UV]
85	3	080T	6	4	6	1	-	2	HV, BL, CRB
85	30	502W	6	2	0	1	-	20	BH, θ
85	31	504W	6	2	2	1	-	44	θ
85	32	218C	5	4	8	1	-	110*	θ, BL
85	79	106V	4	2	0	1	-	12	OBJ
85	82	356B	4	1	6	1	4	-	HV, R/O*
86	27	501D	6	8	0	1	-	20	BH, θ
86	32	113C	6	2	0	1	-	14	
86	52	195B	6	2	0	1	-	41	θ
86	80	507D	4	3	0	1	-	15	R/O*, T
3 SAFETY SHAPE GUARDRAILS									
82	81	503W	11	8	0	2	-	-	θ
84	32	168W	11	3	2	1	-	26	ψ, CMB
86	9	143B	11	1	6	1	-	-	ψ

* Impact Severity (which equals 1/2 m (v sin θ)^2, ft-kips) exceeds test target value of 97 ft-kips (131,532 N•m).

Table 31. Summary of guardrail cases (Continued).

Significant Factors:

θ - impact angle
ψ - yaw angle
BL - low barrier mounting height
BH - high barrier mounting height
CF - component failure
CRB - curb in front of barrier
CRV - curved barrier
HV - heavy vehicle
M - minor impact
OBJ - fixed object too close to barrier
PAD - performed as designed
R/O* - rollover not barrier induced
SNW - snow in front of barrier
T - sloping terrain in front of barrier
U/R - barrier underride
UV - van, utility vehicle
V - impact speed ≥60 mi/h (96 km/h)
WP - weak post barrier

B33 - Barrier Types

1 - cable guardrail G1
2 - W-beam (steel weak post) G2
3 - box beam G3
4 - blocked out W-beam (wood post 8 in by 8 in) G4(1W)
5 - blocked out W-beam (wood post 6 in by 8 in) G4(2W)
6 - blocked out W-beam (steel post) G4(1S)
11 - concrete safety shape

Note: 1 in = 25.4 mm

B66 - Barrier Performance

1 - vehicle redirected
2 - vehicle snagged/pocketed
3 - vehicle overrode barrier
4 - vehicle vaulted barrier
5 - vehicle penetrated barrier
8 - other

B68 - Subsequent Impact

0 - none
2 - another object
6 - rollover
8 - other

B31 - Total number of longitudinal barrier impacts

Other data elements

PSU - Primary sampling unit number
CASE - Case identification number

Table 32. Summary of median barrier cases.

YEAR	PSU	CASE	B33	B66	B68	B31	DRIVER MAIS ≥ 3	IS	SIGNIFICANT FACTORS
1 MB1 CASES									
84	78	253W	13	5	0	1	-	>19	V, ψ
7 MB3 CASES									
82	32	504W	15	3	0	1	-	6	CRB, SNW
82	32	510V	15	1	6		-	2	R/O*, curb on side of road
83	36	514T	15	2	0	1	-	≤1	OBJ
84	32	518W	15	2	0	2	-	-	ψ, BL
84	32	108V	15	2	3	3	-	≤1	ψ
85	33	551D	15	2	0	1	-	71	θ
85	33	556E	15	8	0	1	-	36	θ
6 MB4 CASES									
83	30	525V	17	1	6	1	-	-	BL, CRB
83	39	131V	17	2	0	2	3	-	ψ
83	58	502T	17	2	0	1	-	159*	ψ
83	82	524P	16	4	8	1	-	-	ψ, UV
85	36	526V	17	2	0	1	-	8	V, CRB
86	80	029B	16	1	0	1	3	24	R/O*, LGT
22 CMB CASES									
82	55	504W	18	3	0	2	-	-	ψ
82	82	535K	18	3	3	4	-	-	HV, JK, Before impact (R/O)
82	82	537K	18	1	6	1	-	-	HV, JK, Before impact (R/O)
82	82	561R	18	3	3	2	-	-	MV
82	82	575V	23	1	6	2	-	-	GM, V, CRV
83	3	523W	18	1	6	1	-	-	θ
83	8	509T	18	1	6	1	-	-	V
83	11	508W	18	1	6	5	-	-	V, GM
83	30	164V	18	1	6	1	-	12	39 mi/h (62 km/h)

Table 32. Summary of median barrier cases (Continued).

YEAR	PSU	CASE	B33	B66	B68	B31	DRIVER MAIS ≥3	IS	SIGNIFICANT FACTORS
83	79	509W	18	1	6	1	-	-	V
83	82	521L	18	3	6	1	-	-	V, HV, (T/T)
83	82	530V	18	1	6	1	-	-	θ
84	59	506T	18	1	0	2	-	4	not a failure
84	82	501W	18	3	2	1	-	-	not a failure
85	3	552E	18	1	6	1	-	-	V
85	82	506W	18	8	0	2	U	-	θ, veh. stopped at barrier
86	4	232A	18	1	6	1	fatal	-	V, θ
86	30	054A	18	8	6	1	fatal	-	θ, CF
86	32	506D	18	1	6	1	-	13	R/O*
86	32	507C	18	1	6	2	-	-	V
86	32	509C	18	3	0	1	-	6	ψ, GM
86	82	505B	18	1	2	2	-	-	θ, HIS

* Impact severity (which equals 1/2 m $(v \sin \theta)^2$, ft-kips) exceeds crash test target value of 97 ft-kips (131,532 N•m).

CODES

Significant Factors:

θ - impact angle
ψ - yaw angle
BL - low barrier mounting height
CRB - curb in front of barrier
CRV - curved barrier
GM - General Motors safety shape
HIS - high initial step, MB5SS
HV - heavy vehicle
JK - jackknife
LGT - barrier too short
MV - multiple vehicle
OBJ - fixed object too close to barrier
R/O* - rollover not barrier induced
SNW - snow in front of barrier
UV - van, utility vehicle
V - impact speed ≥60 mi/h (96 km/h)
WP - weak post barrier

B33 - Median Barrier Types

13 - cable, MB1
15 - box beam, MB3
16 - blocked out W-beam (wood post) MB4W
17 - blocked out W-beam (steel post) MB4S
18 - concrete median barrier
23 - other median barrier type

B68 - Subsequent Impact

0 - none
1 - another vehicle
2 - another object
3 - same longitudinal barrier
4 - another longitudinal
5 - bridge rail end
6 - rollover
8 - other

B66 - Barrier Performance

1 - vehicle redirected
2 - vehicle snagged/pocketed
3 - vehicle overrode barrier
4 - vehicle vaulted barrier
5 - vehicle penetrated barrier
8 - other

B31 - Total number of longitudinal barrier impacts

Guardrail, G2

Although snagging/pocketing was coded for all accidents, in two of the cases, the barrier performed as designed although the impact conditions were unusual. An underride of the barrier occurred due to a combination of a large impact angle and a curved barrier geometry. The other accident involved another object collision after a yawing vehicle spun away from the barrier. No serious injuries resulted.

Guardrail, G3

Snagging/pocketing was the most common "failure" mode for three of the five accidents. There were two curb installations (one with a high barrier) and one curved installation. The barrier basically performed as designed for varying factors. There were no serious injuries; none of the cases involved high speed impacts - V > 60 mi/h (96 km/h).

Guardrail, G4

The barrier performance was coded as follows:

- 10 or 36 percent, vehicle snagged/pocketed.
- 8 or 29 percent, vehicle overrode the barrier.
- 4 or 15 percent, vehicle redirected.
- 3 or 11 percent, vehicle vaulted the barrier.
- 2 or 7 percent, vehicle penetrated the barrier.
- 1 or 4 percent, other.

The subsequent impacts were coded:

- 16 or 57 percent, no subsequent impact.
- 7 or 25 percent, vehicle rollover.
- 4 or 14 percent, another longitudinal barrier.
- 1 or 4 percent, other.

In only 1 of the 28 cases did the driver MAIS value exceed 2. In all cases, there were departures from the standard barrier and/or vehicle configurations used in crash test evaluations and these factors were considered as contributing to the barrier performance. Details on each of the 28 cases follows.

Redirected

- All 4 resulted in vehicle rollover:
  - 3 involved pickups; the one rollover that was not barrier-related produced the only MAIS > 2
  - 1 involved a heavy vehicle.

Snagged/Pocketed

- 8 of 10 cases involved no subsequent impacts after snagging:
  - 3 had IS values exceeding the 96 ft-kips (130,176 N•m) test value
  - 4 had impact angles >25°:
    1 with curb
    1 with barrier too high
    1 snagged on object too close to barrier
  - 1 had vehicle/barrier damage incompatibility.
- 2 struck another object.

Overrode Barrier

- 6 of 8 had no subsequent impact after override:
  - 1 rolled over although not coded and not barrier-related
  - 2 had sloping terrain:
    1 rollover not barrier-induced
    1 also had a high θ and ψ
  - 2 with high θ and ψ:
    1 with pickup
    1 with low barrier
  - 1 had snow buildup in front of barrier.
- 1 pickup rollover with a high ψ.
- 1 struck an object too close to barrier.

Vaulted Barrier

- 2 involved low barrier heights:
  - 1 heavy vehicle plus curb (rollover)
  - 1 IS > 96 ft-kips (130,176 N•m) test value plus high θ.
- 1 utility vehicle with high ψ.

Penetrated Barrier

- 1 heavy vehicle/curved guardrail.
- 1 IS > 96 ft-kips (130,176 N•m) test value plus low barrier.

Concrete Safety Shape Guardrail

- 1 stopped in contact with barrier; high θ.
- 1 overrode barrier after the precast barrier segments moved; high ψ.
- 1 was redirected, but rolled over; high ψ.

Median Barrier, MB1

The only case resulted in vehicle penetration of the barrier; high speed and high impact angle contributed to this failure. No serious driver injury reported.

Median Barrier, MB3

4 of the 7 were coded as snagged/pocketed. There were no driver MAIS values > 2.

Redirected

- 1 rolled over after striking curb on opposite side of road.

Snagged/Pocketed

- 3 had no subsequent impact:
  - 1 snagged on object too close to barrier
  - 1 with high ψ and low barrier
  - 1 had high θ.
- 1 had high ψ.

Overrode Barrier

- 1 (snow and curb factors).

Median Barrier, MB4

Two were redirected and three were coded snagged/pocketed.

Redirected

- 2 rolled over:
    - low barrier plus curb
    - barrier too short, rollover not barrier-induced (injury).

Snagged/Pocketed

All three had no subsequent impacts.

- 2 had high ψ:
    - 1 IS > 96
    - 1 driver MAIS > 2.
- 1 curb problem.

Vaulted Barrier

- High ψ plus utility vehicle.

Median Barrier, MB5

There were 22 CMB cases with the following distribution. Only four of the cases had estimated speeds.

- 14 or 64 percent, redirected.
- 6 or 27 percent, overrode barrier.
- 2 or 9 percent, "other" regarding barrier performance.

Redirected

Thirteen of fourteen cases resulted in vehicle rollover. In the other case, the barrier performed as designed. Of the 13 rollover cases:

- 8 were believed to be high speed:
    - 4 high speed only
    - 1 high θ and ψ
    - 2 high θ
    - 1 GM shape.
- 1 had an estimated speed of 39 mi/h (62 km/h), $\theta<25°$, could not explain rollover.
- 1 tractor/trailer was rolling before CMB impact (rollover).
- 1 high θ and ψ.
- 1 high θ (fatal).
- 1 high θ plus high initial barrier step.
- 1 rollover not barrier-related.

Overrode Barrier

Two had no subsequent impact, two struck same barrier, one rolled over, and one struck another object.

- No subsequent impact:
    - 2 high ψ
    - 1 with GM shape.
- Same barrier:
    - 1 tractor/trailer jackknifed and rolled before barrier impact
    - 1 multiple-vehicle impact before barrier impact.
- One tractor/trailer rollover.
- Struck light pole on top of barrier (not a failure).

Other

The two remaining CMB cases coded as "other" for barrier performance included:

- 1 high impact angle where the vehicle stopped in contact with the barrier.
- 1 high impact angle resulted in vehicle rollover after the barrier fractured (fatal).

BARRIER ENDS/TERMINALS

The barrier performance codes for length of need are not necessarily appropriate for terminals. End-on impacts with terminals do not usually result in redirection of the vehicle in the same manner as impact occurring in the length-of-need sections.

BCT Terminal Cases

The "failure" code for the 25 BCT cases included the following:

- 17 snagged/pocketed by barrier.
- 3 penetrated barrier (one resulted in rollovers not barrier-related).
- 4 rollovers, 3 of which were not barrier related.
- 1 accident included minor vehicle damage that was inconsistent with the BCT damage.

BCT accidents coded as redirected were not analyzed further unless problems were noted after the vehicle left the barrier. The accidents are summarized in table 33 where installation deficiencies are also noted.

Spearing and passenger compartment intrusion occurred in four accidents, two of which were broadside impacts.

Turndown W-Beam Guardrail Ends

In the 60 W-beam guardrail ends included in the analysis, the following describes the vehicle performance:

- 3 vaulted the end, returned to the roadway/roadside after riding on top of guardrail.
- 35 vaulted/overrode the end and rolled and/or tumbled.
- 4 vaulted the end and subsequently struck a fixed object near or behind the barrier.
- 2 vaulted and went behind barrier.
- 2 were snagged/pocketed by the end treatment:
    - 1 rolled over.
- 8 vaulted/overrode the end, rode, and came to rest on top of barrier.
- 4 redirected by end:
    - 1 rolled over
    - 3 hit another object.

Table 33. Summary of BCT performance.

Yr	PSU	Case	Installation Problems	Speed > 60 mi/h (96 km/h)	MAIS ≥ 3	Failure Mode	Most Significant Factor
82	02	522W	depressed median	Yes		R/O*	hit guardrail/redirected, hit backside of BCT, rolled over; both barrier impacts appeared to perform as designed (SPEED)
82	82	541V	3-ft by 38-ft flare			S/P	passenger compartment intrusion
83	39	505Q	straight			S/P	low speed impact
83	55	506T	3-ft taper		3	S/P	spearing at left front fender, passenger compartment intrusion
83	82	501T		Yes		S/P	(SPEED) BCT broke away as designed (PAD)
83	82	508V				S/P	yawing vehicle rear end PAD
83	82	512W				S/P	first BCT broke away, vehicle then broadsides another BCT resulting in some passenger compartment intrusion
83	58	509T	straight			S/P	PAD
85	78	501W	flared			PENT	PAD vehicle went behind barrier
86	05	502B	4.2-ft by 26-ft flare (looks proper)			S/P	side impact - passenger compartment intrusion
86	31	503C	3.3-ft by 38-ft flare, trees right next to end				minor vehicle damage inconsistent w/BCT impact
82	80	104T	high, stop taper		4	R/O	anchor cable did not release, but first beam buckled
83	02	017Z				S/P	low speed
83	02	049T		Yes		PENT/ R/O*	vehicle penetrated end, went for considerable distance
84	80	505T				S/P	yawing vehicle spins away

Table 33. Summary of BCT performance (Continued).

Yr	PSU	Case	Installation Problems	Speed > 60 mi/h (96 km/h)	MAIS ≥ 3	Failure Mode	Most Significant Factor
85	04	555D		Yes		PENT	classic BCT excessive speed
85	05	551D				S/P	low speed
84	11	060R	2-ft by 27-ft flare			S/P	yawing vehicle PAD
83	08	213C				R/O*	vehicle glances off downstream BCT
86	04	023B	straight			S/P	yawing, straight BCT, broadside
86	04	057C	high		3	S/P	foundation failure, too high
86	82	097D	high			S/P	vehicle wedges under downstream of end coded 41 in high
86	39	502D	1-ft by 10-ft flare			S/P	vehicle sideswipes BCT
83	55	506T	3-ft taper			S/P	vehicle speared by BCT; passenger compartment intrusion
84	82	505N			fatal	R/O*	truck pulling a car hits guardrail end

Note: Did not record "redirected" impacts unless problem occurred after redirection.

Most Significant Factor:

S/P - snagged/pocketed by barrier
PENT - penetrated barrier
R/O* - vehicle rollover, not barrier-induced
PAD - performed-as-designed
flare - parabolic flare offset
taper - straight lateral offset

1 ft = 0.305 m
1 in = 25.4 mm

- 1 vehicle fuel tank ruptured by top of post contact as vehicle slid along barrier.
- 1 vehicle in process of redirection when loss of barrier height at downstream end induces rollover.

As shown in table 34, the investigators coded either "vaulting" or "overrode" barrier in describing most of the vehicles' interaction with the turndown end.

END CASES, BARRIER FIRST OBJECT STRUCK

A list of barrier end impact cases was compiled that included cases for which a barrier was the first object struck. As summarized in table 35, a total of 353 cases were in this category. Of the 353 cases, there were 111 coded with a turndown end and 36 with a BCT coded end. Further filtering of the data was accomplished by removing those cases that were miscoded or were not W-beam end treatments. This reduced the number to 81 W-beam turndown ends and 35 W-beam BCT ends as shown in table 35. This section considers only W-beam turndown and BCT cases.

Performance Evaluation

A significant number of the W-beam end accidents were coded with no subsequent impact occurring after impacting the barrier. Twenty-five or 31 percent of the turndown accidents were coded accordingly with no driver MAIS values greater than 2. A total of 16 or 43 percent of the BCT cases also fell into this category, although one BCT case was coded as snagging/pocketing and no subsequent impact and a driver MAIS value of 3.

For the turndown ends, the most significant subsequent event was vehicle rollover. As shown in table 36, the 32 rollover events represented not only 40 percent of the turndown accidents, but accounted for one-half of the serious driver injuries and two-thirds of the driver fatalities.

For the BCT, subsequent striking of another object occurred in six or 17 percent of the accidents and four or 11 percent resulted in rollover. The five driver MAIS values > 2 were a result of: (1) three BCT contacts alone, (2) another object contact, and (3) a rollover. The fatal accident vehicle rolled over.

It should be noted that the driver fatality information was based on police-reported data. Most of the MAIS values were "7" or unknown.

Table 34. Summary of turndown end cases.

Yr	PSU	Case	Installation Problems	Speed > 60 mi/h (96 km/h)	MAIS ≥ 3	Failure Mode	Most Significant Factor
82	33	503V					redir, hit wall/pole, tree
82	51	502W				V, R/O	guardrail end
82	51	510V				V	guardrail end, came off guardrail after 125 ft of contact
82	51	518T				S/P	$\theta > 25$, $\psi > 10$
82	78	502V				V	hit culvert after vaulting end
82	78	503T				V, R/O	guardrail end
82	86	501S			FATAL (MAIS=7)	V, R/O	guardrail end
83	10	508W				O/R	vehicle stops on top of guardrail
83	30	523W				V, R/O	guardrail end
83	31	525N	obj. close			V	vehicle broadsides pole while on top of guardrail
83	51	503R				O/R	vehicle on top of barrier to rest for 141 ft
83	51	510W				O/R	vehicle on top of barrier to rest for 30 ft
84	59	515W				O/R	vehicle on top of barrier to rest for 25 ft
84	59	518V				V, R/O	guardrail end
85	31	554C				O/R, R/O	guardrail end
85	36	512W				V, R/O	guardrail end
85	36	523W				V, R/O	guardrail end

Table 34. Summary of turndown end cases (Continued).

Yr	PSU	Case	Installation Problems	Speed > 60 mi/h (96 km/h)	MAIS ≥ 3	Failure Mode	Most Significant Factor
85	36	524V				R/O	ramped W-beam (not twisted) end
85	36	553D	curb			O/R	81 ft to vehicle rest on top of barrier
85	36	554B	obj. close			O/R, R/O	vehicle contacts utility pole while on top of barrier
85	36	556D	curved flare			O/R, R/O	vehicle rolls over
85	36	557D				O/R	vehicle remains upright - passes behind barrier
85	36	562D				V, R/O	vehicle rolls over after guardrail impact
85	53	551B					vehicle redirected off turndown end into bridge rail
85	61	507Y				V, R/O	yaw angle, van
83	78	524V				R/O	yaw angle
83	80	521R				V, R/O	guardrail end
85	36	533V				R/O	vehicle redirected by one guardrail into turndown; rolls over
85	36	551D	6-in curb			V, R/O	guardrail end
85	93	559C				V, R/O	guardrail end
86	03	503D				V	vehicle remains on barrier top after 15 ft
86	10	501D				O/R	vehicle ran up end - only undercarriage damage
86	36	505B			3	O/R, R/O	yawing vehicle goes up end - slides along barrier - tripped by guardrail end into creek
86	78	501C				O/R, R/O	yaw/guardrail end

Table 34. Summary of turndown end cases (Continued).

Yr	PSU	Case	Installation Problems	Speed > 60 mi/h (96 km/h)	MAIS ≥ 3	Failure Mode	Most Significant Factor
82	32	198S			FATAL (MAIS=7)	V, R/O	guardrail end
82	32	220V				V, R/O	guardrail end
82	53	049W				V, R/O	guardrail end
82	77	031T		X		V, R/O	guardrail end
82	84	031S				V, R/O	struck bridge abutment after running up turndown and dropping to channel
83	84	503T				V, R/O	pickup struck bridge abutment after running up turndown and dropping to channel
84	03	502W				V, R/O	guardrail end
84	10	135V				V	stayed on top for 83 ft before leaving guardrail
84	82	510T				V, R/O	guardrail end
86	03	502C				O/R	fire/gas tank rupture - car stayed on top for 90 ft
82	55	284T			3	V, R/O	car rolls 1/4 turn - roof sheared off by sign support
83	28	104T				V, R/O	guardrail end
83	33	151V				V, R/O	guardrail end
83	39	064R				O/R, R/O	low speed
83	77	236W				O/R	stayed on top for 77 ft
84	10	135V				O/R, R/O	guardrail end
84	10	167V				O/R, R/O	guardrail end
84	78	171A				V, R/O	guardrail end

Table 34. Summary of turndown end cases (Continued).

Yr	PSU	Case	Installation Problems	Speed > 60 mi/h 96 km/h	MAIS ≥ 3	Failure Mode	Most Significant Factor
85	26	047V				O/R, R/O	vehicle in process of redirection when loss of barrier height at downstream end allows rollover
85	26	234B			3		redirected at downstream end - went across road, hit tree
85	30	026W		X		V	PAD
85	30	040V				V, R/O	low speed
85	80	551D				O/R	rides on top before returning to roadway shoulder
85	63	502W	dropoff			S/P, R/O	dropoff - vehicle snagged on post tops, R/O
83	93	559C			FATAL (MAIS=6)	V, R/O	guardrail end - fatal
82	51	514V			3	RED, R/O	yawing Pinto spun away, rolled over

Most Significant Factor:

V	- vaulted barrier
S/P	- snagged/pocketed by barrier
R/O	- rollover
O/R	- overrode barrier
PAD	- performed as designed
RED	- redirected

1 ft = 0.305 m
1 in = 25.4 mm

Table 35. Summary of barrier end cases.*

Total End Cases	353
Total Turndown End Treatment (B39 = 3)	111
Total W-beam Turndown End Cases	81
Total Clinical Analysis of Turndown Cases	41**
Total BCT End Treatment (B39 = 4)	36
Total W-beam BCT End Cases	35
Total Clinical Analysis of BCT Cases	13**

* First object struck is barrier.
** These cases are included in previous section analysis.

Table 36. Summary of W-beam end performance.

	Subsequent Impact								Injuries	
Vehicle	(0) None	(2) Object	(3) Same Barrier	(4) Other Barrier	(5) Bridge Rail End	(6) Rollover	(8) Other	Total	Driver MAIS ≥ 3	Driver Fatal
					(a) Turndown					
(1) redirected	10	2	4	2	1	7		26	2	
(2) snagged/ pocketed	1							1		
(3) overrode barrier	12	12		1	1	18	1 (6)	45	1	2
(4) vaulted barrier	1	1				5	1 (6)	8	1	1
(8) other	1							1		
Total	25	15	4	3	2	32	0	81		
Driver MAIS ≥ 3		1			1	2			4	
Driver Fatal		1				2				3

Table 36. Summary of W-beam end performance (Continued).

	Subsequent Impact								Injuries	
Vehicle	(0) None	(2) Object	(3) Same Barrier	(4) Other Barrier	(5) Bridge Rail End	(6) Rollover	(8) Other	Total	Driver MAIS ≥ 3	Driver Fatal
(b) BCT										
(1) redirected	5	1	4	4		3		17	1	1
(2) snagged/ pocketed	6	1				1		8	4	
(3) overrode barrier	1				1			2		
(5) penetrated barrier		1						1		
(8) other	4	3						7		
Total	16	6	4	4	1	4		35		
Driver MAIS ≥ 3	2	2				1			5	
Driver Fatal						1				1

V. SUMMARY

The following is a brief summary of these analyses:

1. From the statistical analyses, it was determined that weak post barriers were less associated with driver injury (MAIS $\geq$ 1) than other barrier types. The same was observed in clinical analyses although the number of weak post cases was small.

2. Driver injury rates (MAIS $\geq$ 1) for trajectories where the vehicle returns to or crosses the roadway were higher than those for remaining on the roadside and remaining on top of, or going through, or over the barrier. It is not clear why remaining on top of, or going through, or over the barrier did not lead to a higher proportion of driver injury.

3. In regard to subsequent impact, rollover produced the highest rate of driver injury (MAIS $\geq$ 1).

4. Higher risks of serious driver injury (A+K, MAIS $\geq$ 3) were associated more with blunt and turndown end treatments than with length of need.

5. Rollover was associated with both higher driver injury (MAIS $\geq$ 1) and serious injury (A+K) rates.

6. Higher risks of serious driver injury (A=K, MAIS $\geq$ 3) were associated more with blunt and turndown end treatments than with length of need.

7. End hits are more likely to result in serious driver injury than LON by being more likely to produce rollover and by producing more serious injuries when no rollovers occur.

8. For turndown barrier-ends, the most significant subsequent event was vehicle rollover.

9. Reconstructed values of longitudinal barrier impact speeds typically have an error margin of ±10 mi/h (16.1 km/h). These speed values also depend largely on the interpretation of the specifics of each accident. This matter is worth some additional study for the purpose of standardizing the procedures involved in accident reconstruction.

10. In many cases, where the barrier reportedly failed, unusual impact conditions created a series of events that departed from the smooth redirection usually observed in full-scale crash tests with these traffic rails.

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