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MICHIGAN DEPARTMENT
OF
STATE HIGHWAYS AND TRANSPORTATION

ANALYSES OF
GUARDRAIL ACCIDENTS
IN MICHIGAN

TSD-243-74

by

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The opinions, findings and conclusions expressed in this report are those of the writers, representing the Michigan Department of State Highways and Transportation, and are not necessarily those of the Michigan Department of State Police nor local police agencies.

Information Retrieval Data

KEY WORDS: Accident Severity, Injuries, Guardrail Design, Roadside Structures.

ABSTRACT: To gain information on the performance of W-beam steel guardrail in accidents, investigating officers filed a supplemental form for each vehicle/guardrail accident on the Michigan State Highway system over a six-month period. Correlation analysis was conducted on the data so obtained for 1,375 single-vehicle/guardrail accidents. The injury rate (proportion of accidents resulting in personal injury) was higher for 12.5 ft (3.81 m) post spacing than for 6.25 ft (1.90 m) spacing. The injury rate was lower for the vehicles that were redirected rather than vaulting or breaking through the guardrail. Approach endings with a flared end shoe had a higher injury rate than did buried end-sections. There was no significant difference in injury rates between approach-end and mid-rail impacts.

REFERENCE: Lampela, Allen A., and Yang, Arthur H., Analyses of Guardrail Accidents in Michigan, Report TSD-243-74, Michigan Department of State Highways and Transportation, Lansing, July 1974.

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The writers wish to acknowledge with appreciation the Steering Committee for Bi-Level Reporting composed of representatives of the Michigan Department of State Police, the County Sheriff organizations, municipal police and the Highway Safety Research Institute at the University of Michigan for their assistance in preparing the study form. The accident information was supplied diligently by investigating officers of all three levels of police agencies.

In 1970 a fourth of all reported Ran-Off-Road accidents on the State Highway road network that resulted in a collision with a fixed object on the roadside involved the guardrail. A disproportionate one-third of the fatalities of all R.O.R. - fixed object accidents occurred in these collisions.

This study was designed to learn from real experience if the design of the guardrail or its placement might be improved by an analysis of the factors involved.

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INTRODUCTION

Purpose of the Study

Guardrails are designed to prevent an errant motorist from driving into areas that are considered unsafe. Guardrails give a motorist a safe recovery by redirecting his vehicle back to the direction of traffic flow or by restraining the vehicle so that it will come to a gradual stop. In an ideal stop the deceleration forces do not cause injuries. The goal has not been attained however since 23 percent of the guardrail accidents result in injuries. Therefore, this in-service guardrail accident study was undertaken for the purpose of obtaining certain intelligence in guardrail design and placement technology that has not been determined from the study of controlled collisions.

To accomplish the purpose of this study, the Michigan Department of State Police's Steering Committee for Bi-Level Reporting, jointly with this Department, developed a supplemental form (Appendix I) for collecting guardrail accident data. The form was filled out by investigating officers at the scene of the accident and attached to the official accident report. It included the angle of impact, speed, result to the impacting vehicle, other objects or vehicles hit, location of impact along the rail, presence of curb, and type of guardrail post and spacing.

The severity of the accident, type of vehicle, area of impact on the vehicle and other pertinent information was acquired from the Official Traffic Accident Report using the Code Sheet (Appendix II). This knowledge with the additional information from the supplemental report was statistically analyzed using a 95 percent confidence level to determine certain functional relationships from which engineering conclusions related to guardrail could be reached.

Data Collection and Method of Evaluation

Approximately 1400 single-vehicle guardrail accidents were recorded during the study period of January 1 to July 1, 1973, in addition to 200 guardrail accidents of the multiple-vehicle type. In the multiple-vehicle accident the guardrail was struck in addition to a collision with another vehicle.

In any single-vehicle guardrail accident, the colliding vehicle may have had rotary motion in addition to sliding and skidding before striking the guardrail. In these accidents the vehicle damage and passenger injuries are guardrail-related. By comparison, in a multiple-vehicle collision the cause of any resulting injury and vehicle damage is due to a series of collisions. It is difficult, if not impossible, to determine which injury and which vehicle damage was caused by a certain impact. Consequently, emphasis was placed on statistical analyses of the single-vehicle guardrail accidents due to the

known relationships and more accurate data. The data was summarized from the Official Traffic Accident Reports and the supplemental Guardrail Study form, and a field review of guardrail-curb accidents to provide the detailed information necessary for accurate analysis.

However, because the variables are not in linear order and since there is difficulty in developing a mathematical model containing the many variables, the data was tabulated and analyzed by pairs, independently. Correlation analysis between vehicle impact speed and angle of collision has been included to coordinate other factors. Appendix III indicates the statistical methods used in the report. It includes (A) 2 x 2 chi-square test to measure the rate difference between two accident groups, and (B) goodness of fit to measure the frequency differences between two accident distributions.

Analyses of the data are continuing. This report will give the engineer some valuable insight to the actions of guardrail in collision, some methods of study, and a chance to seek additional information from this or more data taken at different locations and/or time frames.

If at the scene of the accident some specific information such as angle of impact, or speed or result of impact could not be determined accurately, it had been omitted. Therefore the total number of accidents in any table can vary with the total in the other tables.

CONCLUSIONS

Impact Speeds as Related to Guardrail Accidents

The distribution of impact speeds involving each type of guardrail showed no significant difference nor did the impact speeds of nine types of vehicles studied.

The percentage of guardrail accidents resulting in injuries ranged from 14 percent for impact speeds less than 10 mph to 56 percent for speeds equal to or greater than 70 mph with an increasing rate of change at higher speeds. Also the severity of injuries was determined to be directly proportional to the estimated vehicle impact speed.

The percentage of vehicles stopped or trapped by guardrail decreased monotonically from 67 percent at 10 mph to 17 percent in the 60 to 69 mph and over 70 mph and 70 mph ranges. Redirected back toward roadway type accidents remained stable at about 35 percent for speeds below 50 mph.

Area of Impact on Vehicle and Related Injury Rates

Thirty percent of the accidents occurred with the front, 20 percent with the right front, and 24 percent with the left front. Six percent of the impacting vehicle ultimately resulted in rollovers. Injury rates were: 40 percent head-on, 23 percent right front, 32 percent left front, and 60 percent rollover.

A small percentage of the accidents occurred with the right side (4 percent) and left side (3 percent); the injury rates were 44 and 30 percent, respectively.

Injuries as a Function of Guardrail Types

Injury rate and severity for impacts with Type A guardrail was significantly higher than for the other types of guardrail. (Fig. 4)

There was a significantly higher proportion of injury accidents where the post spacing was 12 ft rather than 6 ft. However, there was no significant difference in the severity of the accidents in either case.

There was a significantly higher proportion of injury accidents when the vehicle resulted in hurdling or going over the rail than in the other vehicle reactions. Also when impacting vehicles broke through the guardrail or were hurdled by it there was a higher fatality rate than when they were redirected, stopped or rode on the guardrail.

Results of Impact as a Function of Guardrail Type

Type C guardrail had a significantly higher percentage of vehicles redirected and stopped or restrained.

Type A had a high percentage of breakthrough and hurdled the guardrail-type accidents.

Functional characteristics of B were superior to A but inferior to Type C guardrail.

Guardrail with steel posts had a higher number of vehicles redirected and a lower proportion of breakthroughs than rail mounted on wood posts. It appears that steel posts may be advantageous over wood posts.

Injury Rate as a Function of Vehicle Type

Differences in the injury rates for the various types of vehicles were not statistically significant. Semi-trucks had a significantly higher fatality rate.

Angles of Impact

The distribution of vehicle types involved at various collision angles did not change appreciably.

There was a consistent drop in the percentage of vehicles redirected as the angle of impact increased; 51 percent for angles less than 10 degrees to 24 percent for angles over 50 degrees. The correlation of speed as a function of impact angle was not strong enough to predict length of guardrail in advance of an object for certain lateral distances as related to speed. There was a significant indication that vehicles at high speeds left the roadway at flatter angles than those traveling at lower speeds.

Curb in Combination Guardrail

The presence of curbs did not show significant evidence of a vehicle being vaulted, hurdled or catapulted over the rail.

There was a notably greater tendency for vehicles to be re-directed.

There was a significantly less chance of a vehicle breaking through the guardrail.

Guardrail Approach Ending

A review of accidents involving two types of guardrail endings (one sloped and anchored to the ground and the other flared with a curved panel without anchorage) reveals a significantly higher injury rate and fatality rate for the flare type of ending.

Thirty-two percent of the vehicles impacting with the flared type ending were stopped or trapped.

A relatively high percentage of vehicles impacting with the sloped end section (32 percent compared to 18 percent for the other) rode either on top or hurdled the rail.

At impact speeds of 40 mph or less no injury accidents resulted with the sloped end section.

There are no significant differences in injury rate and severity distributions of injury between accidents involving the approach end as compared to a midrail section.

RECOMMENDATIONS

Based on the findings of this study it is recommended:

That Type C guardrail be used on all highways exceeding 45 mph running speed exclusive of traffic volume.

That guardrail be anchored to bridge structures and reinforced with additional posts in the immediate proximity for about 12 to 15 ft; to provide a gradual change in stiffness between the two barriers.

That all fragile bridge railings with relatively weak posts and beams be replaced with sloped face concrete safety parapet. An alternative to the slope faced concrete parapet can be continuous W-beams or some other system with structural integrity mounted on posts of adequate strength and reasonable spacing.

That on roadways with speeds of 40 mph and less the sloped-end sections may remain in place.

That a program be adopted for removal of all "exposed" or flared type end shoe sections on the State Highway road system.

That accidents with the Breakaway Cable-Terminal end of guardrail, a recently adopted standard by the Michigan Department of State Highways and Transportation, be evaluated. Since the Type C guardrail is designed with two W-beams, the functional characteristics of BCT may be considerably different than if fastened to a single rail system.

ANALYSES OF THE DATA

Types of Guardrails Studied

Approximately 25 percent of all ran-off-the roadway accidents on Michigan's 9200-mile state highway system involve guardrail. This study has been directed toward the evaluation of collisions with three types of steel beam guardrails: Types A, B and C as shown on Figure A. Type A, the most prevalent, consists of a W-beam that has a top height of 24 in. and is fastened directly to posts that are spaced at 12.5 ft. A redesign of the section (about eight years ago) raised the beam 3 in., doubled the number of posts (spaced at 6.25 ft), and "blocked out" the beam away from the post with the use of 6 in. cantilever blocks (later the blocks were increased to 8 in.). This modified section is specified as Type B guardrail.

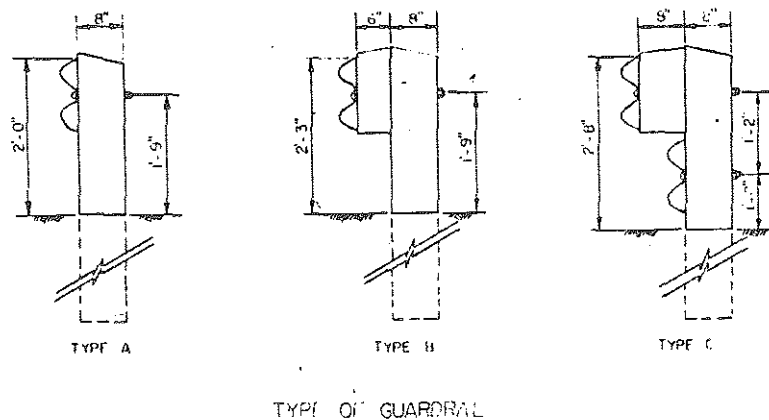


FIGURE A. Types of Steel Beam Guardrail

To further improve the functional characteristics and provide more safety the beam was raised an additional 5 in., the block depth increased to 8 in., and a lower beam fastened directly to the posts. This section is known as Type C.

Distribution of Accidents by Guardrail Type

Frequency of guardrail accidents and related percentages involving each guardrail type are shown in Table 1; 55 percent involved Type A, 20 percent Type B, 12 percent Type C, and 13 percent other types (guard posts, guard posts and cable, bridge rail, concrete median barrier and guardrail fastened to barrels at a construction zone). The others, although some currently classed as obsolete, were retained in the overall evaluation since they represent a percentage of accidents with guards designed to protect the errant motorist.

TABLE 1
DISTRIBUTION OF ACCIDENTS BY IMPACT SPEED
AND TYPE OF GUARDRAIL

<u>Impact Speed</u>	<u>Type A</u>	<u>Type B</u>	<u>Type C</u>	<u>Other</u>	<u>Total</u>
V < 10 mph	6 (0.8)*	4 (1.6)	2 (1.3)	2 (1.2)	14 (1.1)
10 ≤ V < 20	22 (3.4)	13 (5.2)	7 (4.7)	10 (5.8)	52 (4.1)
20 ≤ V < 30	66 (9.3)	22 (8.8)	10 (6.7)	15 (8.8)	113 (8.8)
30 ≤ V < 40	103 (14.5)	43 (17.2)	30 (20.9)	34 (19.9)	210 (16.4)
40 ≤ V < 50	179 (25.2)	44 (17.6)	26 (17.3)	44 (25.7)	293 (22.9)
50 ≤ V < 60	168 (23.7)	58 (23.2)	35 (23.3)	42 (24.6)	303 (23.7)
60 ≤ V < 70	111 (15.6)	42 (16.8)	26 (17.3)	17 (9.9)	196 (15.3)
70 ≤ V	55 (7.7)	24 (9.6)	14 (9.3)	7 (4.1)	100 (7.8)
Total	710 (55)**	250 (20)	150 (12)	171 (13)	1281

*Percentage of column total
**Percentage of line total

To provide specific information on the effectiveness of the various types of guardrails the speeds were grouped into 10 mph increments. Statistical evaluation has proven that there is no difference in the speed distributions, meaning that speed distributions for the accidents involving each type of guardrail are similar. A percentage frequency of the guardrail accidents as related to speed are shown graphically in Figure B.

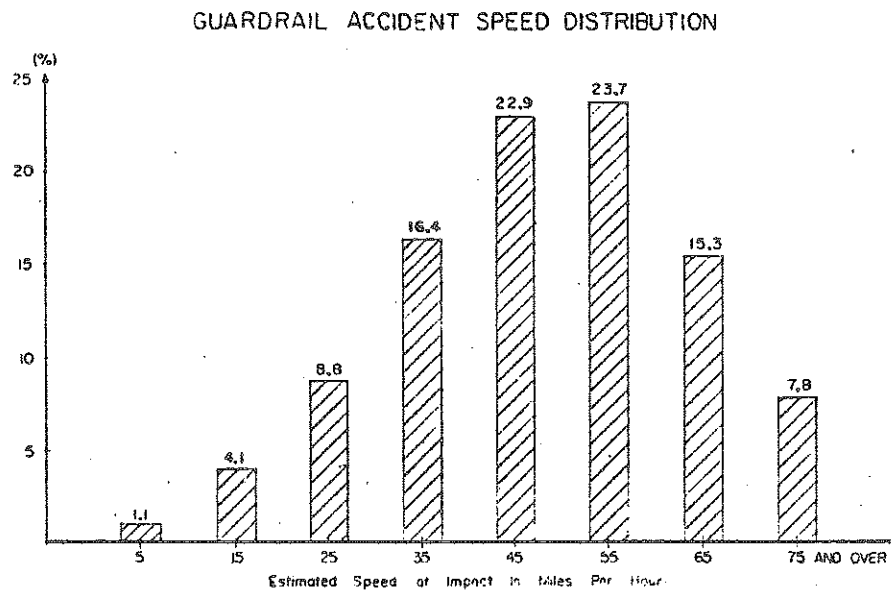


FIGURE B. Distribution of Guardrail Accident
As Related to Speed

Guardrail Accident Severity as a Function of Impact Speed

Guardrail accident severity as a function of impact speed is shown in Table 2. The severity of injuries was determined to be directly proportional to the estimated vehicle impact speed.

The percentage of guardrail accidents resulting in injuries range from 14 percent for impact speeds less than 10 mph to 56 percent for a speed equal to or greater than 70 mph with an increasing rate of change at high speeds. This indicates that guardrails provide motorists with uniform protection during ran-off-roadway accidents with respect to the speed of the impacting vehicle.

Although the injury rate is relatively high at higher speeds, it does not mean that the accident would not have been more severe without guardrail; for example, abutment and pier accidents in 1967, '68, '69 and '70 on Michigan's highways were generally five times as severe as impacts with guardrail.

TABLE 2
ACCIDENT SEVERITY AS A FUNCTION OF IMPACT SPEED
Injury Code*

Impact Speed	K	A	B	C	FD	Total
V < 10 mph	0	1 (7.1)**	0	1 (7.1)	12 (85.7)	14 (1.1)***
10 ≤ V < 20	0	1 (1.9)	4 (7.4)	3 (5.6)	46 (85.2)	54 (4.2)
20 ≤ V < 30	0	3 (2.6)	10 (8.6)	12 (10.3)	91 (78.4)	116 (9.1)
30 ≤ V < 40	1 (0.5)	9 (4.3)	13 (6.2)	18 (8.6)	169 (80.5)	210 (16.4)
40 ≤ V < 50	1 (0.3)	19 (6.6)	29 (10.1)	32 (11.1)	206 (71.8)	287 (22.5)
50 ≤ V < 60	2 (0.7)	29 (9.6)	43 (14.3)	38 (12.6)	189 (62.8)	301 (23.6)
60 ≤ V < 70	4 (2.0)	29 (14.8)	31 (15.8)	29 (14.8)	103 (52.6)	196 (15.4)
70 ≤ V	3 (3.0)	22 (22.4)	18 (18.4)	12 (12.2)	43 (43.9)	98 (7.7)
Total	11 (0.9)**	113 (8.8)	148 (11.6)	145 (11.4)	839 (67.3)	1276

*Injury Code

FD - Property damage.

A - Visible signs of injury, as bleeding, wounded or distorted member, or had to be carried from the scene.

B - Other visible injury, as bruises, abrasion, swelling, limping, etc.

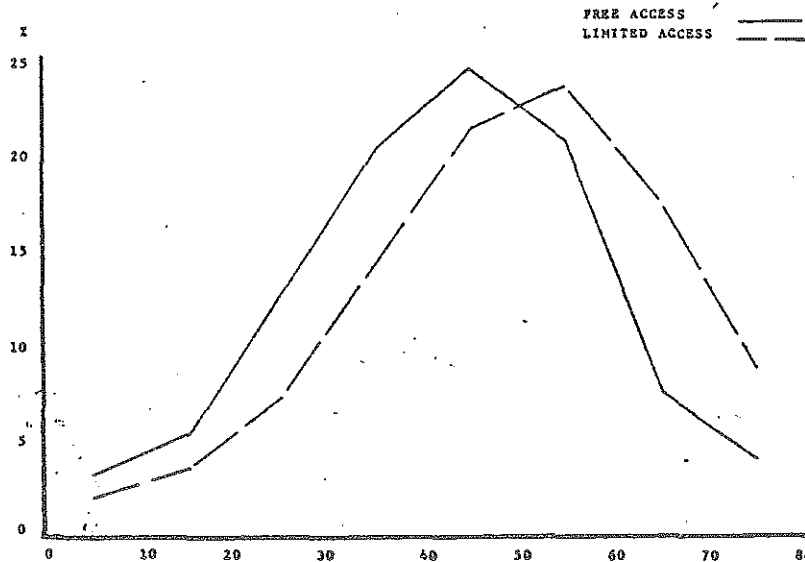
C - No visible injury but complaint of pain or momentary unconsciousness.

K - Fatally injured.

**Percentage of line total

***Percentage of column total

A review of the accident speeds for free and limited access roads (Figure C) indicated that the overall speeds were higher on the limited access routes.



H.P.H.
 Figure C
 Guardrail Accident Speeds For Free And Limited Access Roads

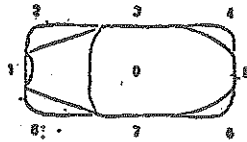
Injuries as Related to Area of Impact on the Vehicles

The sketch noted as the impact code shown below Table 3 identifies the area of damage by the initial impact with guardrail and/or the major resulting dominant characteristic, such as rollover of the vehicle in the accident. The table shows that of all the guardrail accidents, 6 percent were rollover (designated by "0" in the sketch), 30 percent collided with the guardrail at position 1 (front), 20 percent at position 2 (right front side), and 24 percent at position 8 (left front side). The remainder of the accidents were distributed among the other impact areas in percentages varying from 3 to 5.

TABLE 3
ACCIDENT SEVERITY AS A FUNCTION OF IMPACT
AREA ON VEHICLE

Impact Code (see sketch)	Injury Code					TOTAL
	X	A	B	C	PD	
Rollover	0 (1.4)*	13 (18.8)	14 (20.3)	13 (18.8)	28 (40.6)	69 (5.9)**
Front	1 (2.0)	36 (10.1)	51 (14.3)	46 (12.9)	216 (60.7)	356 (30.5)
Right Front	2 (0.4)	17 (7.1)	21 (8.8)	15 (6.3)	184 (77.3)	238 (20.4)
Right Side	3	0 (12.5)	6 (12.5)	9 (18.7)	27 (58.2)	48 (4.3)
Right Rear	4	0 (1.6)	1 (1.6)	3 (4.8)	57 (91.9)	62 (5.3)
Rearend	5	1 (3.3)	1 (3.3)	2 (6.7)	3 (10.0)	23 (76.7)
Left Rear	6	0 (2.3)	1 (2.3)	0	3 (6.8)	40 (90.9)
Left Side	7	0 (10.0)	4 (10.0)	3 (7.5)	5 (12.5)	28 (70.0)
Left Front	8	1 (0.4)	23 (8.3)	34 (12.2)	31 (11.2)	189 (68.0)
TOTAL	11 (0.9)	102 (8.7)	132 (11.3)	128 (11.0)	792 (68.0)	1163

*Percentage of line total
**Percentage of column total



There were no fatal accidents when vehicles hit guardrails at positions 3, 4, 6 and 7; these impacts contributed to approximately 18 percent of all the guardrail accidents.

The highest percentage of impacts (30 percent) occurred with the front. This appears reasonable since the majority of the vehicles would make first contact with the front bumper unless the vehicle was in some degree of rotating and/or sliding motion.

The higher number of impacts with the left front (24 percent) as compared with the right front (20 percent) indicates that

a relatively high number of the vehicles went off the road on the left side. It is reasoned that vehicles travel faster in the median lane or when passing on two-way roads and therefore tend to go out of control and off the traveled-way to the left.

Injury rates for the three areas with the highest number of impacts are 40 percent head-on, 23 percent right front and 32 percent left front.

Rollover accidents are not limited to impacts with the approach end when the vehicle is hurdled; they may occur during high-speed high-angle impacts with the mid-section of guardrail. In this case the guardrail may deflect excessively causing the vehicle to pocket and to be rapidly redirected (either or both laterally and vertically) with high impact forces that can send the vehicle ultimately into a roll or spin.

Right-front impacts can be expected to occur with shallow angles since the vehicle is in the outside lane near the guardrail and result in lower deceleration forces. The percentage of injuries (23 percent) in this type of accident was relatively low.

Although the driver is sometimes thought of as being in the safest seat during a collision, this does not appear to be necessarily so with impacts to the left front. There the

the driver is in proximity to the vehicle impact area and is susceptible to injury from crushing and deflection of the vehicle hardware.

In the rear-end accident the wayward vehicle had to hit the guardrail with relatively direct backward motion, otherwise a right rear or left rear impact would have occurred.

During right- or left-side accidents, deflection and crushing of the vehicle body hardware against the occupants is quite likely; the result being the high percentages of injuries, 44 and 30 percent for the right and left sides, respectively. In comparison there were injuries in only 8 percent of the right-rear and 9 percent of the left-rear type accidents. In these accidents guardrail contact generally was of the glancing type with low impact forces.

It can be concluded that there is a high potential for serious injuries and a high rate of injuries for rollover (60 percent), head-on (40 percent), right side (44 percent), left side (30 percent) and left front (32 percent).

The preceding comments, concerning rail impact with various areas of the vehicles and related injuries, are representative of a large sample; the result and effect of any specific type of accident could vary extensively with other accidents of a similar type.

Accident Severity as a Function of Guardrail Types

One of the important objectives of the study was to determine the effectiveness of each type of steel beam guardrail, i.e. Types A, B and C. Table 4 shows the relationship of the severity of injuries to the types of guardrail involved. Although there was no significant difference in the severity of accidents among the types of guardrails, the injury rate however was significantly higher for the Type A rail. These rates were 36 percent for A, 32 percent for B and 26 percent for Type C guardrail.

TABLE 4
ACCIDENT SEVERITY AS A FUNCTION OF TYPE GUARDRAIL

Type of Guardrail	Injury Code					TOTAL
	K	A	B	E	FB	
A	10 (1.4)*	69 (9.6)	94 (12.8)	89 (12.1)	471 (64.2)	733 (55.4)**
B	1 (0.4)	19 (7.3)	32 (12.3)	30 (11.5)	179 (60.3)	261 (19.7)
C	1 (0.7)	15 (10.0)	12 (8.0)	11 (7.3)	111 (74.0)	150 (11.3)
OTHER	2 (0.1)	11 (6.1)	17 (7.5)	23 (12.8)	126 (70.6)	179 (13.5)
TOTAL	14 (1.1)	114 (8.6)	158 (11.7)	153 (11.6)	887 (67.0)	1323

*Percentage of line total
**Percentage of column total

A cause for the higher number of injuries could be the 12.5 ft post spacing characteristic of Type A guardrail. The spacing is too long for the stiffness of the beam to sustain an impact without deflecting excessively and resulting in pocketing as the rail fails in lateral strength. With decreased post spacing (6.25 ft), typical of Type B and C guardrails, 12-gauge W-beam provides a stiffer system that should result

in a smoother redirection of the wayward vehicle. Table 5 indicates that injury rates were 27 percent and 35 percent for the 6- and 12-ft nominal post spacings, respectively. Statistically there was a significantly higher proportion of injury accidents where the post spacing was 12 ft. There was no significant difference in the severity of injuries however with either the 6- or 12-ft post spacing.

TABLE 5
ACCIDENT SEVERITY AS A FUNCTION OF POST SPACING

Post Spacing	Injury Code					TOTAL
	K	A	B	C	FD	
6 ft	1 (0.3)*	22 (6.0)	36 (9.7)	38 (10.8)	258 (73.3)	352 (30)**
12 ft	11 (1.3)	76 (9.3)	105 (12.9)	96 (11.3)	533 (65.0)	820 (70)
TOTAL	12 (1.0)	97 (8.3)	140 (11.9)	132 (11.3)	791 (67.5)	1172

*Percentage of line total
**Percentage of column total

Another reason for the higher injury rate for the Type A guardrail could be caused by the undercarriage of the impacting vehicle snagging a post. This results from the post rotating during the impact and thus exposing the lower portion and making it vulnerable to wheel and hub contact. The offset blocks that are characteristic of Type B guardrail are designed to reduce or eliminate snagging. Generally snagging of the undercarriage by the post causes higher deceleration forces to the impacting vehicle.

The other types involved 34 percent guard posts and cable and guard posts. These are often for the purpose of guiding

the motorist and not necessarily in front of massive obstacles so when the vehicle does go through the result is not an injury type impact.

Result of Impact as a Function of Guardrail Type

In an evaluation of the impact effects with type of guardrail, the Type A had a relatively high percentage of Broke through Guardrail (8 percent) and Hurdled the Guardrail (14 percent) types of accidents (See Table 6). Going over the rail is conducive to a higher injury rate, as shown in Table 4, because of the resultant tumbling and rolling of the vehicle or because of a subsequent collision with a fixed object. The tendency of an impacting vehicle of going over the Type A guardrail appears to justify raising of the beam in Types B and C guardrails to reduce the susceptibility of an impacting vehicle from mounting and going over the rail.

TABLE 6
RESULT OF IMPACT AS A FUNCTION OF GUARDRAIL TYPE
Type of Guardrail

Result of Impact	A	B	C	Other	Total
Redirected back to roadway	281 (37.9)*	120 (45.8)	81 (53.3)	57 (31.0)	539 (40.2)
Stopped or trapped by guardrail	208 (28.0)	74 (28.2)	57 (37.5)	53 (28.8)	392 (29.2)
Broke through guardrail	59 (8.0)	10 (3.8)	2 (1.3)	49 (26.6)	120 (9.0)
Hurdled the guardrail	101 (13.6)	22 (8.4)	6 (3.9)	13 (7.1)	142 (10.6)
Rode on top of guardrail	93 (12.5)	36 (13.7)	6 (3.9)	12 (6.5)	147 (11.0)
TOTAL	742 (55.4)**	262 (19.6)	152 (11.3)	184 (13.7)	1340

*Percentage of column total
**Percentage of line total

Ninety-one percent of the vehicles impacting with Type C were either redirected or stopped and restrained; the

combined percentages were 66 for Type A and 74 for Type B. Eight percent of the vehicles broke through Type A, one percent broke through Type C. Fourteen percent hurdled and 12 percent rode on top of Type A; for Type C these results were approximately 4 percent, respectively.

The Type C design is meant to allow the vehicle's tire to run under the upper rail during high angle and high velocity impacts, thus reducing the tendency of a vehicle to roll-over and from being directed abruptly into the traffic stream. Simultaneously, the lower beam is intended to act as a rub rail and prevent snagging of the posts. These design characteristics of the Type C appear to be a partial reason for the lower injury rate.

In general, the operational characteristics of Type B were superior to Type A but inferior to Type C.

Result of Impact as a Function of Post Type

Wood posts have been reasoned to be superior to steel because there is more bearing surface against the soil and therefore a reduced tendency for shirting. Wood has also been reasoned to be more resilient in sustaining an impact.

A review of Table 7 however reveals that rail mounted on steel posts had a higher number of vehicles redirected and a lower proportion of breakthroughs. The breakthroughs

may have resulted to a certain degree because of the wood having deteriorated; some of the guardrail has been in place for ten years or more. Perhaps the steel posts have more energy absorbing capacity than wood posts. It appears that posts of steel may be used in place of wood.

TABLE 7
RESULT OF IMPACT AS A FUNCTION OF POST TYPE

Result of Impact	Type of Post		
	Wood	Steel	Total
Redirected back to roadway	247 (38.6)*	242 (44.4)	489 (41.3)
Stopped or trapped by guardrail	198 (31.0)	153 (28.1)	351 (29.3)
Broke through guardrail	56 (8.8)	22 (4.0)	78 (6.6)
Hurdled the guardrail	65 (10.2)	65 (11.9)	130 (11.0)
Rode on top of guardrail	73 (11.4)	63 (11.6)	136 (11.5)
TOTAL	639 (54.0)**	545 (46.0)	1184

*Percentage of column total
**Percentage of line total

Distribution of Accidents by Impact Speed and Vehicle Type

Guardrail accidents included a distribution of nine types of vehicles...passenger to service vehicles. This distribution revealed the following percentages: 45 percent full-size, 21 percent intermediate, 15 percent compact, 5 percent sportscar, 6 percent pick-up and panel and 4 percent semi-truck combinations (Table 8).

An evaluation of speed distributions of the most prevalent types - full, intermediate and compact size passenger vehicles - (constituting 82 percent of the sample) shows that there are no significant differences in speed distributions of all vehicles in this study.

TABLE 8
DISTRIBUTION OF ACCIDENTS BY IMPACT SPEED
AND VEHICLE TYPE

Vehicle Type	Full Size	Intermediate	Compact	Sportscar	Station, Bus Carryall	Jeep Type	Pickup or Panel	Single unit, Dump van, Flatbed, etc.	Truck, Tractor (semi)	Other or unknown	TOTAL
Impact Speed	0	1	2	3	4	5	6	7	8	9	TOTAL
< V < 10 mph	42 (6.7)*	14 (4.8)	7 (3.3)	8 (11.3)	0	1 (16.7)	6 (8.0)	4 (15.4)	5 (8.9)	0	87 (6.3)
10 ≤ V < 20	26 (4.2)	12 (4.1)	10 (4.7)	0	0	0	3 (4.0)	1 (3.8)	3 (5.4)	0	55 (4.0)
20 ≤ V < 30	58 (9.3)	27 (9.3)	15 (7.1)	4 (5.6)	1 (8.3)	0	6 (8.0)	2 (7.7)	4 (7.1)	0	117 (8.5)
30 ≤ V < 40	101 (16.2)	43 (14.8)	33 (15.6)	6 (8.3)	1 (8.3)	1 (16.7)	13 (17.3)	5 (19.2)	9 (16.1)	1 (50.0)	213 (15.5)-
40 ≤ V < 50	128 (20.5)	66 (22.7)	44 (20.9)	13 (18.3)	3 (25.0)	2 (33.3)	14 (18.7)	8 (30.9)	18 (32.1)	1 (50.0)	297 (21.6)
50 ≤ V < 60	141 (22.6)	60 (20.6)	51 (24.2)	16 (22.5)	5 (41.7)	2 (33.3)	13 (17.3)	4 (15.4)	14 (25.0)	0	306 (22.3)
60 ≤ V < 70	80 (12.8)	44 (15.1)	39 (18.5)	18 (25.4)	1 (8.3)	0	13 (17.3)	1 (3.8)	3 (5.4)	0	199 (14.5)
70 ≤ V	49 (7.8)	25 (8.4)	12 (5.7)	6 (8.5)	1 (8.3)	0	7 (9.3)	1 (3.8)	0	0	101 (7.3)
TOTAL	625 (45.5)**	291 (21.2)	211 (15.3)	71 (5.2)	12 (0.9)	6 (0.4)	75 (5.5)	26 (1.9)	56 (4.1)	2 (0.1)	1375

*Percentage of column total
**Percentage of line total

Accident Severity as a Function of Vehicle Type

Injury rates of all types of vehicles varied from 20 percent to 41.7 percent: station, bus and carryall had the highest rate; single-unit truck 38.5 percent; semi-truck 37 percent and compact car 36.4 percent; full size, intermediate and pickup or panel had rates of 32 percent; however, the injury rate differences were not statistically significant.

(Table 9).

Semi-trucks had significantly higher fatality rates due to a greater number of these large vehicles going through the

TABLE 9
ACCIDENT SEVERITY AS A FUNCTION OF VEHICLE TYPE
INJURY CODE

Vehicle Type	K	A	B	C	ED	TOTAL
Full Size	7 (1.1)*	57 (9.3)	65 (10.6)	66 (10.8)	416 (68.1)	611 (45.4)**
Intermediate	1 (0.3)	19 (6.6)	29 (10.3)	42 (14.6)	194 (68.3)	287 (21.3)
Compact	2 (1.0)	16 (7.8)	31 (15.0)	26 (12.5)	131 (63.6)	206 (15.3)
Sportscar	0	8 (11.6)	10 (14.5)	5 (7.2)	46 (66.7)	69 (5.1)
Station bus, carryall	0	4 (33.3)	0	1 (8.3)	7 (58.3)	12 (0.9)
Jeep type	0	1 (20.0)	0	0	4 (80.0)	5 (0.4)
Pickup or panel	2 (2.6)	4 (5.3)	11 (14.7)	7 (9.3)	51 (68.0)	75 (5.6)
Single unit, dump van, flatbed, etc.	0	2 (7.7)	4 (15.4)	4 (15.4)	16 (61.5)	26 (1.9)
Truck tractor (semi)	2 (3.7)	7 (13.0)	7 (13.0)	4 (7.4)	34 (63.0)	54 (4.0)
Other or not known	0	0	0	0	2 (100.0)	2 (0.1)
TOTAL	14 (1.0)	118 (8.8)	157 (11.6)	155 (11.5)	903 (67.0)	1347

*Percentage of line total
**Percentage of column total

guardrail. The ratio of the tractor weight to the gross weight (particularly when loaded) and the related kinetic energy is so great that survival due to the crushing effect of the load against the driver compartment is improbable.

On most passenger vehicles the engine (the concentrated load) is in front with the power train fastened to it. The remainder of the weight consists of only relatively light hardware surrounding the passenger compartment. Thus during longitudinal impacts the occupants are not crushed by a shifting or sliding of a load from behind as with a loaded truck.

Table 10 displays distribution of nine vehicle types at angles of collision in 10-degree increments. Almost one-third of the impacts occurred at angles of 10 degrees or

less. There was a relatively uniform decrease in the percentage of vehicles involved as the angles of impact increased as shown in Figure D.

TABLE 10
ANGLES OF IMPACT BY VEHICLE TYPES

Vehicle Type	Angle of Collision						TOTAL
	0°-10	11°-20	21°-30	31°-40	41°-50	51° and over	
Full size	208 (48.0) ^a	139 (46.3)	111 (45.1)	85 (43.4)	41 (44.1)	41 (38.3)	625 (45.5)
Intermediate	86 (19.9)	59 (19.7)	60 (26.4)	39 (19.9)	22 (23.7)	25 (23.4)	291 (21.2)
Compact	60 (13.9)	49 (16.3)	37 (15.0)	35 (17.9)	16 (17.2)	14 (13.1)	211 (15.3)
Sportscar	17 (3.9)	15 (5.0)	16 (5.7)	13 (6.6)	4 (4.3)	8 (7.5)	71 (5.2)
Station, bus, carryall	3 (0.7)	1 (0.3)	4 (1.6)	2 (1.0)	2 (2.2)	0	12 (0.9)
Jeep type	2 (0.5)	1 (0.3)	1 (0.4)	0	1 (1.1)	1 (0.9)	6 (0.4)
Pickup or panel	28 (6.5)	15 (5.0)	11 (4.5)	9 (4.6)	2 (2.2)	10 (9.3)	75 (5.4)
Single unit, dump, van, flatbed, etc.	7 (1.6)	8 (2.7)	0	5 (2.6)	3 (3.2)	3 (2.8)	26 (1.9)
Truck tractor (semi)	22 (5.1)	13 (4.3)	8 (3.3)	7 (3.6)	2 (2.2)	4 (3.7)	56 (4.1)
Other or unknown	0 (0)	0 (0)	0 (0)	1 (0.5)	0	1 (0.9)	2 (0.1)
TOTAL	438 (31.5) ^{a*}	300 (21.9)	246 (17.9)	196 (14.2)	93 (6.8)	107 (7.8)	1375

^aPercentage of column total
^{a*}Percentage of line total

(%) DISTRIBUTION OF ANGLES OF IMPACT WITH GUARDRAIL

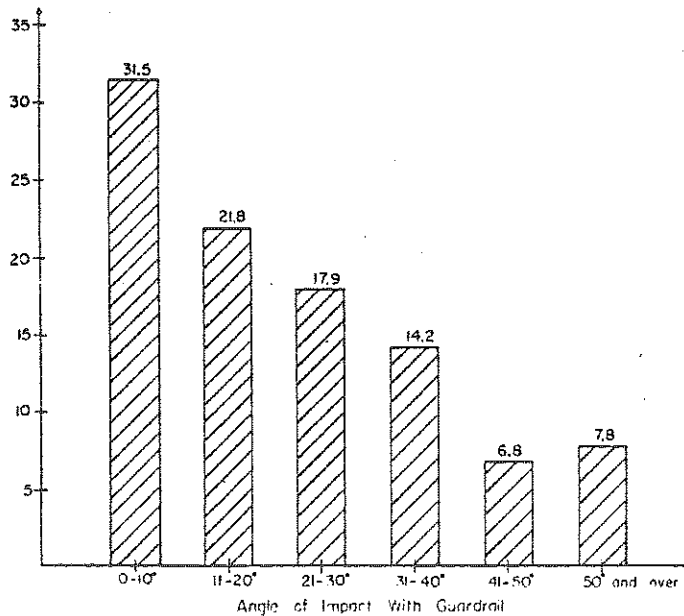


FIGURE D. Distribution of Guardrail Accidents As Related to Angles of Impact

Result of Impact as a Function of Impact Speed

Speed has an important role in affecting the reaction of the impacting vehicles in guardrail accidents. (Table 11). It appears that percentages of Stopped or Trapped by Guardrail type accidents are monotonically decreasing from 67 percent at less than 10 mph to 17 percent in the 60 to 69 mph and over 70 mph ranges. It also indicates that Redirected Back to Roadway type accidents stay relatively stable at about 35 percent at speeds below 50 mph. At higher speeds the percentage increased to about 45 percent. At speeds higher than 30 mph Break Through the Guardrail type accidents remained in a spread between 6 and 9 percent.

TABLE 11
RESULT OF IMPACT AS A FUNCTION OF IMPACT SPEED

Result of Impact	Impact Speed (MPH)								TOTAL
	0 to 9	10 to 19	20 to 29	30 to 39	40 to 49	50 to 59	60 to 69	70 & over	
Redirected back to roadway	3 (25.0)*	15 (33.3)	34 (33.7)	68 (38.0)	96 (38.4)	121 (45.7)	84 (46.4)	40 (43.5)	461 (41.0)***
Stopped or trapped by guardrail	8 (66.7)	25 (55.5)	46 (45.3)	66 (36.9)	76 (30.4)	68 (25.7)	30 (16.6)	16 (17.4)	335 (29.8)
Broke through guardrail	1 (8.3)	2 (4.6)	3 (3.0)	13 (7.3)	20 (8.0)	16 (6.0)	11 (6.1)	8 (8.7)	74 (6.6)
Hurdled the guardrail	0	0	8 (7.9)	13 (7.3)	18 (7.2)	28 (10.6)	41 (22.6)	18 (19.6)	126 (11.2)
Road on top of guardrail	0	3 (6.7)	10 (9.9)	19 (10.6)	40 (16.0)	32 (12.1)	15 (8.3)	10 (10.9)	129 (11.5)
Total	12 (1.1)**	45 (4.0)	101 (9.0)	179 (15.9)	250 (22.2)	265 (23.5)	181 (16.1)	92 (8.2)	1125

*Percentage of column total
**Percentage of line total
***Percentage of column total

Result of Impact as a Function of Impact Angle

The effectiveness of guardrail and the result of the collision to the impacting vehicles were evaluated similarly as with speed. With the exception of angles between 41 and

50 degrees, there was a consistent drop in the percentage of vehicles redirected as the impact angle increased. The percentages ranged from 49 percent for the angles less than 10 degrees to 24 percent for angles over 50 degrees. No distinct trends were detected as related to angles of impact in the performance of the guardrail. (Table 12).

TABLE 12
RESULT OF IMPACT AS A FUNCTION OF IMPACT ANGLE

Result of Impact Impact	Impact Angle						TOTAL
	0 to 10	11 to 20	21 to 30	31 to 40	41 to 50	51 & Over	
Redirected back to roadway	172 (48.6)*	122 (47.3)	81 (39.7)	63 (36.9)	31 (38.3)	23 (23.5)	492 (42.2)
Stopped or trapped by guardrail	101 (28.5)	61 (23.6)	52 (25.5)	54 (31.6)	37 (45.7)	44 (44.9)	349 (29.9)
Broke through guardrail	20 (5.6)	18 (7.0)	13 (6.4)	9 (5.3)	1 (1.2)	15 (15.3)	76 (6.5)
Hurdled the guardrail	31 (8.7)	26 (9.3)	35 (17.1)	27 (15.8)	4 (4.9)	10 (10.2)	131 (11.2)
Rode on top of guardrail	30 (8.5)	39 (17.8)	23 (11.3)	18 (10.3)	8 (10.0)	6 (6.1)	118 (10.1)
TOTAL	354 (30.4)**	258 (22.1)	204 (17.5)	171 (14.7)	81 (6.9)	98 (8.4)	1166

*Percentage of column total
** Percentage of line total

It is conceivable that there is no distinct pattern in guardrail performance for a certain impact angle or a small spread of impact angles since the accidents occurred in a wide range of speeds, in any of eight general areas of vehicles, and in some cases where the guardrail was in combination with curb.

Accident Severity as a Function of Angle

Of all the guardrail accidents the following are percentages of vehicles impacting at various angles: 31 percent occurred at angles of 10 degrees or less, 22 percent from 11 degrees to 20 degrees, 18 percent from 21 degrees to 30 degrees, 14

percent from 31 degrees to 40 degrees, 7 percent from 41 degrees to 50 degrees and 8 percent over angles of 50 degrees. Table 13 displays accident severity distribution and type of injury due to various angles of collision.

TABLE 13
ACCIDENT SEVERITY AS A FUNCTION OF IMPACT ANGLE

Impact Angle	Injury Code					TOTAL
	K	A	B	C	PD	
0°-10°	6 (1.4)*	32 (7.6)	48 (11.4)	54 (12.8)	281 (66.7)	421 (31.4)**
11°-20°	2 (0.7)	30 (10.2)	35 (11.9)	28 (9.5)	200 (67.8)	295 (21.9)
21°-30°	3 (1.3)	26 (10.0)	20 (8.4)	36 (14.2)	158 (66.1)	239 (17.7)
31°-40°	2 (1.0)	18 (9.3)	25 (12.9)	19 (9.8)	130 (67.0)	194 (14.4)
41°-50°	0	7 (7.6)	8 (8.7)	8 (8.7)	69 (75.0)	92 (6.8)
51° and over	0	7 (6.7)	21 (20.0)	12 (11.4)	65 (61.9)	105 (7.8)
Total	13 (0.9)	110 (8.8)	157 (11.7)	155 (11.5)	903 (67.1)	1366

*Percentage of line total
**Percentage of column total

There is a significant indication that vehicles at high speeds left the roadway at flatter angles than those traveling at lower speeds. The correlation of speed as a function of impact angle however was not strong enough to predict adequate length of guardrail in advance of an object for certain lateral distances as related to speed.

Severity as a Function of Result of Impact

Of all the single-vehicle guardrail accidents, 42 percent were redirected back to the roadway, 29 percent were stopped or trapped, 5.5 percent broke through, 11 percent were hurdled and 11.5 percent rode on top of guardrail. (Table 14).

TABLE 14
ACCIDENT SEVERITY AS A FUNCTION OF RESULT OF IMPACT

Result of Impact	Injury Code					Total
	K	A	B	C	PD	
Redirected back to roadway	4 (0.8)*	43 (9.2)	52 (10.6)	56 (11.4)	134 (68.0)	491 (42.3)**
Stopped or trapped by guardrail	1 (0.3)	23 (7.5)	33 (9.9)	33 (9.3)	241 (72.4)	333 (28.7)
Broke through guardrail	2 (2.6)	11 (14.5)	6 (7.9)	7 (9.2)	50 (65.8)	76 (6.5)
Hurdled the guardrail	3 (2.4)	16 (12.7)	20 (15.9)	23 (18.2)	64 (50.8)	126 (10.9)
Rode on top of guardrail	1 (0.7)	7 (5.2)	21 (15.7)	11 (8.2)	36 (70.1)	134 (11.5)
Total	11 (0.9)	104 (9.0)	132 (11.4)	130 (11.2)	783 (67.5)	1160

*Percentage of line total
**Percentage of column total

In these various categories injuries resulted in 32 percent of those redirected back to roadway, 28 percent stopped or trapped by guardrail, 34 percent broke through guardrail, 49 percent hurdled the guardrail, and 30 percent in rode on top of guardrail. There was a significantly higher proportion of injury accidents in the hurdled the guardrail type than in the others.

There was no significant differences in the severity of injuries (when comparing the percentage of Type A injuries to Types B and C) in the various results of impacts.

Vehicles that broke through the guardrail or were hurdled had a higher fatality rate than when they were redirected, stopped or rode on the guardrail.

Curb in Combination with Guardrail

There are two general classes of curbs: mountable or barrier. The mountable is usually lower with a relatively graduate ascending slope (Figure E, Types B and D); the barrier is usually higher with a vertical (Type K) or relatively steep face

TYPICAL CONCRETE CURB
& GUTTER DESIGNS

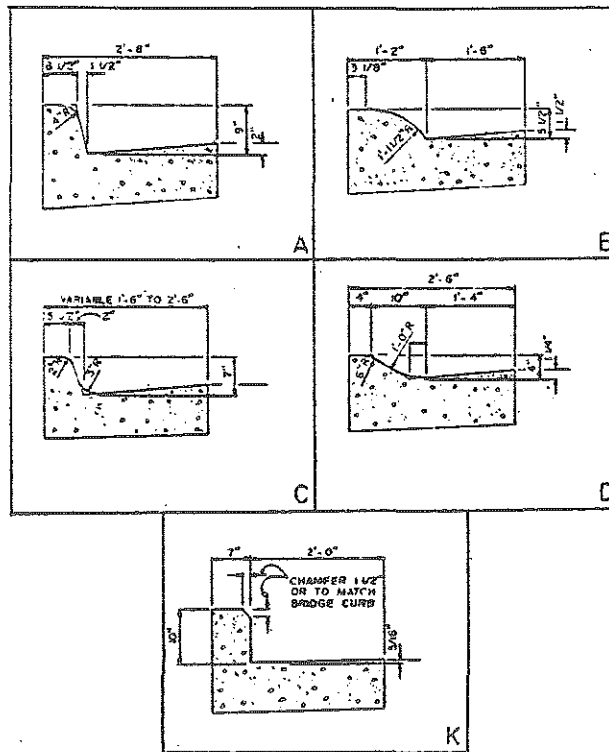


FIGURE B. Typical Concrete Curb and Gutter Designs

(Types A and C). The barrier is not considered as a barricade but as definite demarcation and control of normal traffic movement.

Both types confine roadway water runoff, restrain ease of traffic movement to some degree and serve to delineate the edge of roadway. At least one purpose of curb, and the primary purpose of guardrail, is redirecting the impacting vehicle. Curb redirects by wheel contact only, guardrail redirects with both vehicle body and wheel contact.

Sometimes guardrail is used in combination with curb for redirection and restraint of wayward vehicles. Usually

during low speed small angle impacts the curb redirects with little, if any, vehicle damage. During larger angle and high speed impacts, where the impacting vehicle mounts the curb, it has been proffered that the curb tends to act as a vaulting device, causing the vehicle to bounce or jump. This results in an impact with the adjacent guardrail at a higher than normal elevation, perhaps in some instances directing the vehicle over the rail.

Result of Impact as a Function of Curb

In a review of 212 guardrail accidents that also involved curb, 7.5 percent of the impacting vehicles went over the rail; without curb the percentage was 12 percent. Table 15* involves W-beam guardrail accidents only; other types of guards have been excluded. There was significantly less chance of the vehicle riding on top or breaking through the

TABLE 15

Impact Effects With and Without Curb

<u>Result of Impact</u>	<u>Without Curb</u>	<u>With Curb</u>	<u>Total</u>
Redirected back to roadway	375 (39.7)*	107 (50.5)	482 (41.7)
Stopped or trapped by guardrail	270 (28.6)	69 (32.5)	339 (29.3)
Broke through guardrail	57 (7.1)	4 (1.9)	71 (6.1)
Hurdled the guardrail	113 (12.0)	16 (7.5)	129 (11.2)
Rode on top of guardrail	119 (12.6)	16 (7.5)	135 (11.7)
TOTAL	944 (81.7)**	212 (18.3)	1156

*Percentage of column total

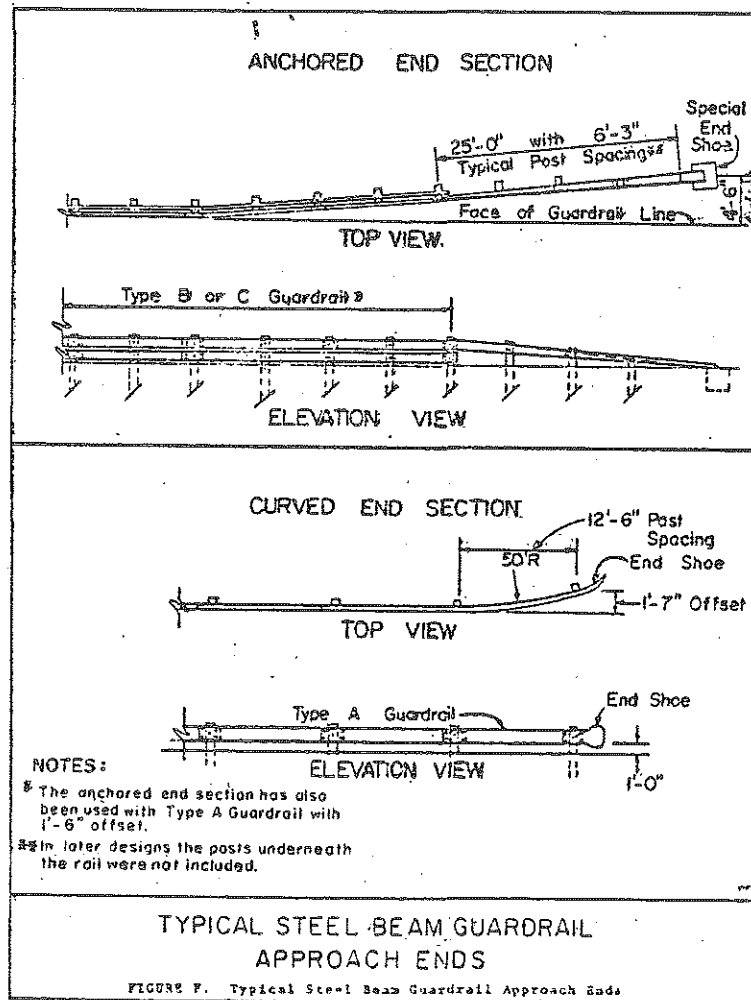
**Percentage of line total

*This result and other curb impact results agree with those in the report Investigation of the Dynamic Impact on Roadside Obstacles, College of Engineering, Wayne State University, Detroit, Michigan (1972).

rail. Also a significantly higher percentage of the vehicles were redirected and stopped where curb was present. Evaluation of accidents involving a combination of curb and guardrail is continuing. Results will be in a subsequent report.

Types of End-Sections

Two types of guardrail approach ends were studied; one being sloped and anchored to the ground surface (popularly known as the Texas Twist) and the other terminating with a curved panel and an end shoe without anchorage. (Figure F).



The W-beam, because of its stiffness to resist lateral deflection, also is very rigid in resisting end impacts and has the potential of spearing. The 50-ft radius end panel, to which the end shoe is fastened, has been designed to redirect a vehicle or to collapse thus decelerating the vehicle over a distance. From the study of the impacts it is not readily conceivable what length of the guardrail was damaged in stopping specific vehicles.

The purpose of the sloped-end is to eliminate spearing of the impacting vehicle and provide longitudinal strength to the guardrail. There is however the probability of vaulting during high speed impacts. Obviously the purpose of the guardrail to absorb energy is lost if the vehicle is airborne.

Result of Impact as a Function of Guardrail End-Section

Table 16 reveals that 32 percent of the vehicles impacting with the flared type ending were stopped or trapped. One of these impacts resulted in a fatality. In another instance the vehicle was speared, cutting off the driver's leg.

TABLE 16
Result of Impact as a Function of Guardrail

Result of Impact	End-Section		Total
	Sloped	Flared	
Redirected back to roadway	25 (38.5)*	65 (38.7)	90 (38.6)
Stopped or trapped by guardrail	14 (21.5)	54 (32.1)	68 (29.2)
Broke through	5 (7.7)	19 (11.3)	24 (10.3)
Hurdled the guardrail	12 (18.5)	12 (7.1)	24 (10.3)
Rode on top of guardrail	9 (13.8)	18 (10.7)	27 (11.6)
TOTAL	65 (27.9)**	168 (72.1)	233

*Percentage of column total

**Percentage of line total

There were three other fatalities where the impact was with the end or within 25 ft of the end (Table 17): one mounted and went over the rail into a pier; in another the vehicle impacted 25 ft from the end, was hurdled, continued down an embankment and the victim was pinned under the car; and in a third the vehicle (semi-truck) impacted 15 ft from end, broke through and hit a pier.

TABLE 17
Accident Severity As A Function of Types of End Section

Type of End Section	Injury Code					Total
	K	A	B	C	PD	
Sloped & Anchored End	0	6* (9.4)	8 (12.5)	3 (4.7)	47 (73.4)	64** (27.8)
Michigan End Shoe	4 (2.4)	13 (7.8)	15 (9.0)	24 (14.3)	110 (66.3)	166 (72.2)
Total	4 (1.7)	19 (8.3)	23 (10.0)	27 (11.7)	157 (68.3)	230

*Percentage of line total
**Percentage of column total

For a brief description of these and other fatal accidents see Appendix IV.

About 28 percent of the end impacts (within 25 ft of the beginning) were with the sloped ending. A relatively high percentage of vehicles impacting with the sloped end section (32 percent compared to 18 for the other) either rode onto or hurdled the rail.

The use of the sloped end appears permissible on lower speed roads where there is a lower potential for the vehicle to become airborne, overturn or tumble, and impact with the obstacle if riding on the rail.

At impact speeds below 40 mph or less no injury accidents resulted with the sloped-end section.

The injury rate and the fatality rate were both higher for the flared type ending.

Accident Severity as a Function of Location of Impact on Guardrail

Table 18 shows injury rates of 32 percent for guardrail approach end collisions and 34 percent for collisions elsewhere along the guardrail. Evaluation of these collisions proved that there are no significant differences in injury rate and severity distributions of injury between accidents involving the approach end as compared to a mid-rail section. The 25-ft point was chosen since that includes the length of sloped-anchored type ending.

Table 18
Accident Severity As A Function of Location of Impact on Guardrail

Impact Loc.	Injury Code					Total
	K	A	B	C	PD	
Within 25 ft. of Leading End	4* (1.7)	19 (8.3)	23 (10.0)	27 (11.7)	157 (68.3)	230** (19.7)
Beyond 25 ft. of Leading End	8 (0.8)	88 (9.4)	115 (12.3)	105 (11.2)	620 (66.2)	936 (80.3)
Total	12 (1.0)	107 (9.2)	138 (11.8)	132 (11.3)	777 (66.6)	1166

*Percentage of line total
**Percentage of column total

The accidents beyond the 25-ft point do include accidents at the trailing end just in advance of a structure. Unless the rail is anchored to the structure and reinforced with additional posts for a distance of 12 to 15 ft, the rail

during impact is often deflected or displaced exposing the structure to a direct impact. These direct impacts usually result in serious injuries and could be partial cause for the higher accident rate beyond the 25-ft point.

A review of Tables 15 and 16 show that 11.2 percent of the total impacts with steel beams were hurdled; the percentage hurdled for the end-sections is 10.3 percent. An inspection of Table 6 indicates that 13.6 percent of the vehicles with Type A rail were hurdled, 8.4 percent with B and only 3.9 percent with C Type rail. It can be concluded that the Type A rail (top height of 24 in. and sometimes less if settlement has occurred) has a higher potential for hurdling of impacting vehicles than Types B or C guardrail.

Suggestions for Improvement of the Study Form

Since it is likely that guardrail studies will continue, the following are suggestions for improvement in the study form (Appendix V):

- Item 3b: the word trapped be replaced with contained.
- Item 6: was curb placed in front of or near the guardrail? Removal of the word near eliminates a decision by the recorder. Near could indicate a short distance in advance of or beyond the point of impact at the guardrail.
- Item 7: Estimate distance between point of vehicle impact and guardrail beginning or ending. Since the primary concern is the beginning, it should be spelled out as approach end. Although impacts near the trailing end are of importance particularly when at the approach to an obstacle such as bridge railing, abutment or pier, these details are generally revealed in the drawing and description on the related official accident report.

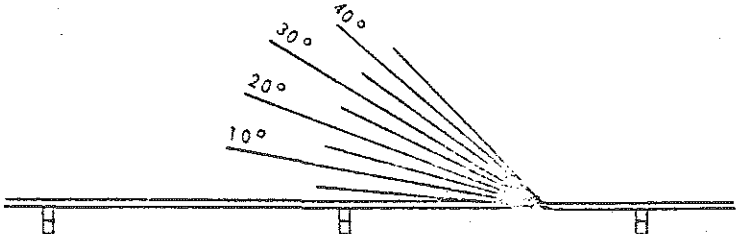
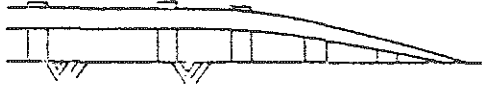

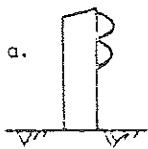
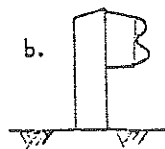
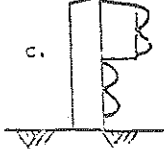
Item 9: the cross sections should have a beam and block shown (dashed) on the opposite side since double-faced guardrails are used in median areas. This eliminates an unnecessary decision during recording since the double-faced might be recorded as other which it is not. Also add below word other: sketch or explain.

Additional Study and Research

Obviously guardrail is a hazard and should be used only when striking it is less severe than striking the object or leaving the roadway. Therefore, the goal is to use the least amount of guardrail without sacrificing the safety of the errant motorist. Since vehicles travel slower on many of the state highways and since the study indicates that there is some correlation of speed as a function of impact angle, the area needs further study and research to provide the maximum utility to Michigan's continuing roadside safety program.

APPENDIX I

Guardrail Study Form 1508

<p>1. Estimate angle of collision with guardrail</p> 	<p>Place an "X" over the box or boxes, and fill in each blank line, as relates to items 1-11.</p>
<p>2. Estimate vehicle speed at impact</p>	<p>_____ mph</p>
<p>3. Was vehicle Did vehicle</p> <p>a. Redirected back to roadway b. Stopped or trapped by guardrail c. Break through guardrail d. Hurdle the guardrail e. Ride on top of guardrail</p>	<p><input type="checkbox"/> a <input type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> d <input type="checkbox"/> e</p>
<p>4. Did vehicle collide with other vehicle or object besides guardrail?</p>	<p><input type="checkbox"/> Yes <input type="checkbox"/> No</p>
<p>5. What other object was hit?</p> <p>a. motor vehicle c. tree b. bridge pier d. other</p>	<p><input type="checkbox"/> a <input type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> d</p>
<p>6. Was curbing placed in front of or near the guardrail?</p>	<p><input type="checkbox"/> Yes <input type="checkbox"/> No</p>
<p>7. Estimate distance between point of vehicle impact and guardrail beginning or ending</p>	<p>_____ FT.</p>
<p>8. Type of end section</p> <p>a.  b. </p>	<p><input type="checkbox"/> a <input type="checkbox"/> b</p>
<p>9. Cross section of guardrail</p> <p>a.  b.  c.  d. Other</p>	<p><input type="checkbox"/> a <input type="checkbox"/> b <input type="checkbox"/> c <input type="checkbox"/> d</p>
<p>10. Post spacing a. 3 ft. b. 6 ft. c. 12 ft.</p>	<p><input type="checkbox"/> a <input type="checkbox"/> b <input type="checkbox"/> c</p>
<p>11. Type of guardrail post a. wood b. steel</p>	<p><input type="checkbox"/> a <input type="checkbox"/> b</p>

APPENDIX II

State of Michigan
Official Traffic Accident Report
and
Coding Key

UD-10 (1-71) State of Michigan OFFICIAL TRAFFIC ACCIDENT REPORT	Department	DO NOT USE
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Location	County	City	Twp.	Date	Time
	Route No.	Name	Fl. Mi. N S E W	Intersection	Route No.

Vehicle #1	State	Drivers License	DOB	Hazardous Action	HBD	HN	Test
	Driver No. 1	First	M.	Last	Address	City	State
	Age	Sex	Inj.				
	Year	Make	Type	Trailer	Reg.	Yr/State	Removed to/by

Seat Position		Name					Address			Pos	Age	Sex	Inj.		
1	2	3													
4	5	6													

Total Occupants	Local Use/Owner	Injured taken to
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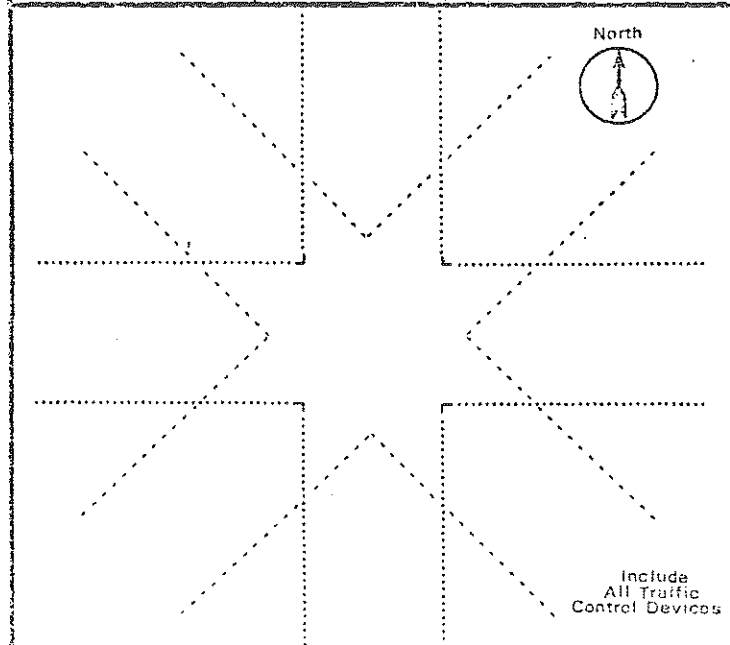
Vehicle #2	State	Drivers License	DOB	Hazardous Action	HBD	HN	Test
	Driver No. 2	First	M.	Last	Address	City	State
	Age	Sex	Inj.				
	Year	Make	Type	Trailer	Reg.	Yr/State	Removed to/by

Seat Position		Name					Address			Pos	Age	Sex	Inj.		
1	2	3													
4	5	6													

Total Occupants	Local Use/Owner	Injured taken to
-----------------	-----------------	------------------

WEATHER <input type="checkbox"/> Clear <input type="checkbox"/> Rain <input type="checkbox"/> Fog <input type="checkbox"/> Cloudy <input type="checkbox"/> Snow	LIGHT <input type="checkbox"/> Day <input type="checkbox"/> Dark <input type="checkbox"/> Dawn <input type="checkbox"/> Dusk <input type="checkbox"/> Street Lights	ROAD SURFACE <input type="checkbox"/> Dry <input type="checkbox"/> Snowy <input type="checkbox"/> Icy <input type="checkbox"/> Wet <input type="checkbox"/> Other	ROAD CONDITION <input type="checkbox"/> Engineering <input type="checkbox"/> Maintenance <input type="checkbox"/> Construction Zone	VISION OBSTRUCTION <input type="checkbox"/> Vehicle #1 <input type="checkbox"/> Vehicle #2 <input type="checkbox"/> None (Explain)	VEHICLE DEFECTS <input type="checkbox"/> Vehicle #1 <input type="checkbox"/> Vehicle #2 <input type="checkbox"/> None (Explain)
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IMPACT CODE Veh. #1 Veh. #2 Total Veh.	TOTAL LANES <input type="checkbox"/> Divided <input type="checkbox"/> Limited Access	DRIVER RE-EXAM. <input type="checkbox"/> Driver #1 <input type="checkbox"/> Driver #2	Damage Property Other Than Vehicles Owner _____ Address _____
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ACCIDENT DESCRIPTION & REMARKS	
Describe all unusual conditions and circumstances	

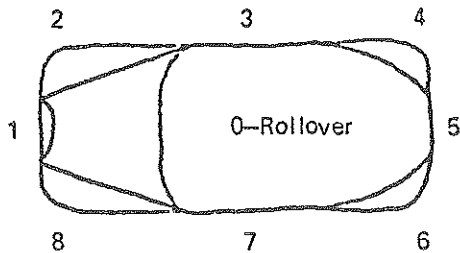
Date Received	Time	Investigators	1 <input type="checkbox"/> 2 <input type="checkbox"/> POLICE ACTION <input type="checkbox"/> Cited for Hazardous Vio. <input type="checkbox"/> Cited for Other Violation <input type="checkbox"/> No Enforcement Action <input checked="" type="checkbox"/> Investigated at Scene	Reviewer
Comp. Status <input type="checkbox"/> open <input type="checkbox"/> closed				

INTERMEDIATES	SPORTS CARS
AMERICAN MOTORS REBEL REBEL SST	THE MACHINE
CHRYSLER DODGE CORONET DELUXE DODGE CORONET 440 DODGE CORONET 500 PLYMOUTH BELVEDERE PLYMOUTH SATELLITE PLYMOUTH SPORT SATELLITE	SUPER BEE R-T ROAD RUNNER GTX
FORD FORD FAIRLANE FORD TORINO MERCURY MONTEGO & MX	COBRA CYCLONE
GENERAL MOTORS BUICK SKYLARK CHEVROLET CHEVELLE MALIBU OLDSMOBILE F-85 & CUTLASS PONTIAC TEMPEST PONTIAC LEMANS	GS SS 396 442 GTO JUDGE

VEHICLE MAKE

TRUCKS	PASSENGER CARS
20 Chevrolet	00 American Motors
21 Diamond T	01 Buick
22 Dodge	02 Cadillac
23 Federal	03 Chevrolet
24 Ford	04 Chrysler
25 GMC	05 Dodge
26 International	06 Ford
27 Mack	07 Imperial
28 Peterbilt	08 Jeep
29 Reo	09 Lincoln
30 White	10 Mercury
31 Willys	11 Oldsmobile
32 thru 38 not assigned	12 Plymouth
39 Other Trucks	13 Pontiac
SPECIAL VEHICLES	14 Volkswagen
40 Motorcycles	15 Not assigned
41 School Bus	16 Not assigned
42 Commercial Bus	17 Not assigned
43 Farm Equipment	18 Other foreign
44 Construction Equip.	19 Other domestic
45 Fire Equipment	
46 Ambulance, Hearse	
47 Police Equipment	
48 Snowmobile	
49 Other or not known	
50 Dune Buggy	

IMPACT CODE



VEHICLE TYPE

0 Full size
1 Intermediate
2 Compact
3 Sports car
4 Carryall
5 Jeep type
6 Pickup or panel
7 Straight Truck, Dump, Van, Flat Bed, Etc.
8 Truck Tractor (semi)
9 Other or not known

Identify the area of damage by the position of the **FIRST IMPACT ONLY** for each vehicle.

In chain reaction accidents, the vehicles in the center shall show resulting damage to both front (1) and rear (5).

CODE OF INJURY

- K—FATAL INJURY—Any injury which results in death.
- A—INCAPACITATING INJURY—Any injury other than fatal which prevents normal activities and generally requires hospitalization.
- B—NON-INCAPACITATING INJURY—Any injury not incapacitating but evident to others at the scene.
- C—POSSIBLE INJURY—No visible injury but complaint of pain or momentary unconsciousness.
- O—NO INJURY—No indication of injury.
(Refer to training manual for injury details)

LOCAL USE/OWNER

Identify the owner when other than driver. This line may be used by local departments for additional information-witnesses, insurance co., etc.

DRINKING CONDITION

- HBD—Had been drinking
- HN—Had not been drinking
- TEST—When chemical test is taken record the results in the test space.
Record officer's considered opinion for each driver and pedestrian when no test taken

HAZARDOUS ACTION

Indicate the specific violation for each pedestrian, bicyclist, or driver which contributed most to the accident. Record only the specific violation even though no enforcement action is taken.

POLICE ACTION

Hazardous Violation — That moving violation which contributed to the cause of the accident. Ex. (left of center - disregard stoplight/sign, careless or reckless driving, DUI, etc.)

Other Violation — Those violations which are present at the scene of the accident, but do not contribute to the cause. Ex. (No Operators License on person, No Proof of Insurance, etc.)

No Enforcement Action — To be checked X when after investigation no violation was indicated and no enforcement action taken.

SPECIAL ATTENTION

1. Review your report for completeness.
2. The following items **MUST** be included in,
 - a. Drinking Condition
 - b. Violation
 - c. Police Action
 - d. Refer to the Training Manual for Details

APPENDIX III

Statistical Methods Used

Statistical Methods Used in the Report

(1) 2 x 2 Chi Square Test

Data

	Class 1	Class 2
Population 1	A_{11}	A_{12}
Population 2	A_{21}	A_{22}

Assumptions:

1. Each sample is a random sample.
2. The two samples are mutually independent.
3. Each observation may be categorized either into class 1 or class 2

Hypotheses: Let the probability that a randomly selected element will be in class 1 be denoted by P_1 in population 1 and P_2 in population 2.

$$H_0: P_1 = P_2$$

$$H_1: P_1 > P_2$$

Test Statistics

$$T = \frac{(A_{11}A_{22} - A_{12}A_{21})^2 (A_{11} + A_{12} + A_{21} + A_{22})}{(A_{11} + A_{12}) (A_{21} + A_{22}) (A_{11} + A_{22}) (A_{12} + A_{21})}$$

(2) The Chi-Square Test for Goodness of Fit

Data: The data consist of n independent observations of a random variable X . These n observations are grouped into c classes and the numbers of observations in each class are presented in the form $1 \times c$ contingency table.

Assumptions:

1. The sample is a random sample.
2. The measurement scale is at least nominal.

Hypotheses: Let $F(x)$ be the true but unknown distribution function of X and let $G(x)$ be some completely specified distribution function, the hypothesized distribution function.

$$H_0: F(x) = G(x) \quad \text{for all } x$$

$$H_1: F(x) \neq G(x) \quad \text{for at least one } x$$

Test Statistics:

Let Q_j be the probability of a random observation on x being in class j , under the assumption that $G(x)$ is the distribution function of x . Then define E_j as

$$E_j = Q_j N, \quad j = 1, 2, \dots, C$$

Then the test statistic is given by

$$T = \sum_{j=1}^C \frac{(f_j - E_j)^2}{E_j}$$

APPENDIX IV
Summary of Fatal Accidents

Summary of Fatal Accidents

There were 14 fatal accidents with guardrails during the study period. The following is a brief summary:

1. Description: Excessive speed resulted in the vehicle striking guardrail and going end-over-end coming to rest on a concrete culvert. The guardrail was struck about 25 ft from the end.

Guardrail Type: A

End Section Type: Curved end

2. Description: Excessive speed resulted in the driver losing control of the vehicle. The vehicle hit the guardrail 56 ft from the end and then followed the guardrail for 143 ft and flipped over onto the opposing traffic lane. The guardrail was struck 25 ft from the beginning of the end section.

Guardrail Type: A

End Section Type: Curved end

3. Description: Excessive speed resulted in the vehicle striking the guardrail, being redirected, striking the guardrail again and going over the rail, rolling down an embankment and landing on its top in a swamp. The guardrail was first struck 59 ft from the beginning of the end section.

Guardrail Type: A

End Section Type: Curved end

4. Description: Excessive speed resulted in the vehicle striking and going over the guardrail. The guardrail was struck 85 ft from the beginning of the end section.

Guardrail Type: A

End Section Type: Curved end

5. Description: The driver lost control of the vehicle causing it to hit the median guardrail; it was then redirected across the median and hit a bridge pier. There was no guardrail at the pier. The guardrail was struck 130 ft from the beginning of the end section.

Guardrail Type: A

End Section Type: Curved end

6. Description: A tire blew out causing the vehicle to leave the roadway, enter the median and break through the guardrail and then strike a concrete pillar. The guardrail was struck 15 ft from the beginning of the end section.

Guardrail Type: A

End Section Type: Curved end

7. Description: Due to excessive speed the vehicle went off the left side of the roadway and first hit the trailing end of guardrail and then a bridge abutment. The railing was not attached to the abutment and collapsed. The vehicle hit the guardrail 96 ft from the beginning of the end section and 24 ft from the bridge structure.

Guardrail Type: A

End Section Type: Curved end

8. Description: The vehicle passed another vehicle on the median while traveling at an excessive rate of speed. The vehicle then came back across the roadway and struck the guardrail and bridge pier, and it was then redirected back across the road. The guardrail was struck 41 ft from the beginning of the end section.

Guardrail Type: A

End Section Type: Curved end

9. Description: The vehicle was going at a rate of speed too fast for conditions; it passed another vehicle, lost control, struck the guardrail and followed it to a bridge support. The guardrail was struck at the beginning of the end section.

10. Description: The vehicle ran off the roadway and hit the beginning of the guardrail end section. The guardrail went through the vehicle.

Guardrail Type: A

End Section Type: Curved end

11. Description: At an excessive rate of speed the vehicle slid into the guardrail backwards, rolled over, became airborne and landed in a creek on its top. The guardrail was struck 50 ft from the beginning of the end section.

Guardrail Type: A

End Section Type: Curved end

12. Description: The vehicle was traveling too fast for conditions as it came around a curve. The driver lost control and the vehicle slid sideways, hit the guardrail, flipped over and went down a hill.

Guardrail Type: Guardposts

End Section Type: None

13. Description: Traveling at an excessive rate of speed the driver lost control of the vehicle. The vehicle struck and rode onto the curb header, then the guardrail, then the bridge railing, then went over the bridge railing into a river and burst into flames.

Guardrail Type: Guardposts

End Section Type: Trailing end at the structure

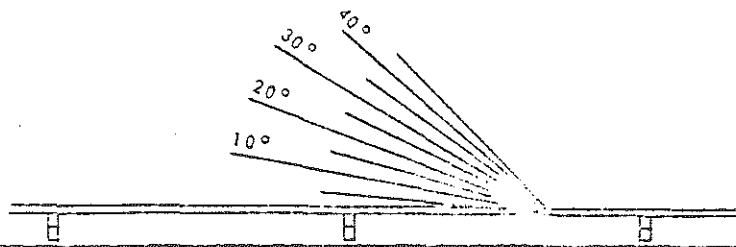
14. Description: Vehicle struck guardrail 166 ft north of (overpassing) crossover or U-turn structure, slid along guardrail, then jumped it, landing on right side and caught fire. Vehicle approximately 25 ft south of crossover (overpass).

Guardrail Type: CD

End Section Type: Curved end

APPENDIX V
Suggested Revision Of
Guardrail Study Form

1. Estimate angle of collision with guardrail



Place an "X" over the box or boxes, and fill in each blank line, as relates to items 1-11.

2. Estimate vehicle speed at impact

_____ mph

3. Was vehicle
Did vehicle

- a. Redirected back to roadway
- b. Contained by guardrail
- c. Break through guardrail
- d. Hurdle the guardrail
- e. Ride on top of guardrail

a b c d e

4. Did vehicle collide with other vehicles or object besides guardrail?

Yes No

5. What other object was hit?

- a. motor vehicle
- b. bridge pier
- c. tree
- d. other

a b c d

6. Was curbing placed in front of the guardrail

Yes No

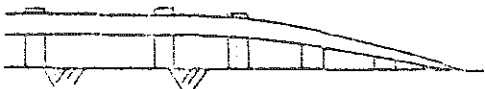
7. Estimate distance between point of vehicle impact and guardrail approach end.

_____ FT.

8. Type of end section

a.

b.



a b

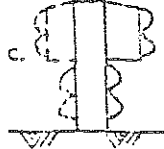
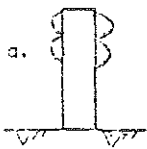
9. Cross section of guardrail

a.

b.

c.

d. Other
(sketch or explain)



a b c d

10. Post spacing a. 3 ft. b. 6 ft. c. 12 ft.

a b c

11. Type of guardrail post a. wood b. steel

a b