Report No. FHWA/RD-82/139

ACCIDENT ANALYSIS OF HIGHWAY NARROW BRIDGE SITES

VOLUME II. TECHNICAL DOCUMENTATION

February 1983

FINAL REPORT

SwRI Project 06-4941

Prepared for

Federal Highway Administration and
National Highway Traffic Safety Administration
U.S. Department of Transportation
Washington, D.C. 20590

SAN ANTONIO, HOUSTON, TEXAS, AND WASHINGTON, D.C.

FOREWORD

This report presents research findings on the characteristics associated with accidents at narrow bridge sites, including the extent of the problem, bridge site characteristics, bridge accident characteristics, and their relationships. This work was sponsored by the Federal Highway Administration and the National Highway Traffic Safety Administration under Contract No. DOT-FH-11-9285.

Five States participated in this study and contributed hard copy, photolog, and computer data for generation of the data files. The authors are indebted to those State personnel who helped in this effort.

The direction and guidance of the Contract Managers, Mr. Philip Brinkman for FHWA and Mr. Nicholas G. Tsongos for NHTSA, are gratefully acknowledged. Appreciation is also given to Mr. James V. Boos and Mrs. Kumud Mathur of FHWA and Mr. Gary Toth and Mr. F. J. Daniels of NHTSA who served as Contract Managers during the course of the study. The authors also wish to acknowledge the FHWA ADP Services in providing data processing to this study, particularly Mr. William Mellott, Mr. Jim Heminger, and Ms. Susan Trefry.

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-82/139		

4. Title and Subtitle ACCIDENT ANALYSIS OF HIGHWAY NARROW BRIDGE SITES-Volume II. Technical Documentation	5. Report Date February 1983 6. Performing Organization Code SwRI-03-4941
7. Author(s) K. K. Mak, L. R. Calcote	8. Performing Organization Report No. SwRI-4941
9. Performing Organization Name and Address Southwest Research Institute 6220 Culebra Road, P.O. Drawer 28510 San Antonio, Texas 78284	10. Work Unit No. 31K2-042 11. Contract or Grant No. DOT-FH-11-9285
12. Sponsoring Agency Name and Address Federal Highway Administration and National Highway Traffic Safety Administration U.S. Department of Transportation Washington, D.C. 20950	13. Type of Report and Period Covered Final Report July 1977-February 1983 14. Sponsoring Agency Code

15. Supplementary Notes

FHWA Contract Manager: Mr. Philip Brinkman (HSR-20)
NHTSA Contract Manager: Mr. Nicholas G. Tsongos (NRD-32)

16. Abstract

This research was conducted to determine (1) the extent of the accident problem associated with narrow bridge sites, (2) the relationships between frequency and severity of accidents to the design, geometry, and condition of the bridges and their approaches, and (3) characteristics of accidents at bridge sites. Environmental and accident data at bridge sites were studied from five States (Arizona, Michigan, Montana, Texas, and Washington). Sources of data consisted of FHWA bridge inventory and accident files, State photologs and computerized and manual files, and site visits. Also, 125 accidents involving collisions with bridge ends, railings, and transition treatments were investigated in depth. The POPULATION file (11,880 bridges) was used to determine the extent of the narrow bridge accident problem and the associated accident frequencies, rates, and distributions. The SAMPLE file (1,989 bridges selected from the POPULATION file for in-depth study) was used to determine the relationships of various physical and traffic characteristics to accident rates and severities. The ACCIDENT file (124 investigated accidents) was used to determine the characteristics and the relationships between accident and injury severity for accidents at bridge sites.

This report is the second volume of a three-volume final report. This volume includes the data collection and analysis procedures and technical documentation of the results. Volume I contains the executive summary and Volume III contains the supporting appendices.

17. Key Words	18. Distribution Statement
Narrow Bridges, Highway Safety, Bridge Accident Analysis	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	206	

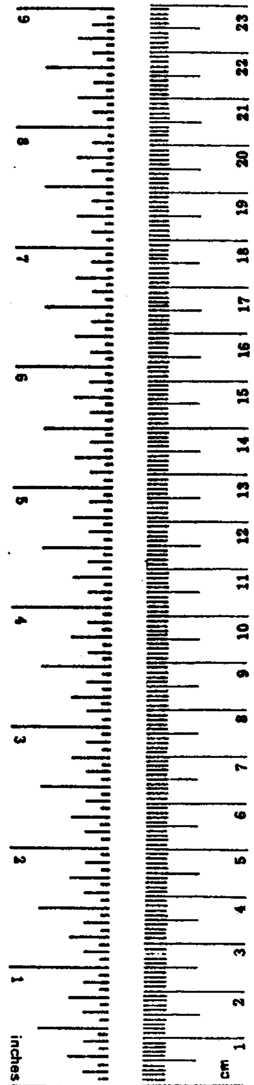
Form DOT F 1700.7 (8-69)

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

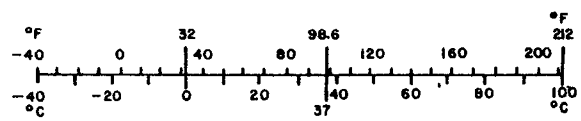


TABLE OF CONTENTS

		Page
I.	INTRODUCTION AND RESEARCH APPROACH	1
	1.1 Statement of the Problem	1
	1.2 Program Objectives and Scope	5
	1.3 Research Approach	8
II.	POPULATION FILE	12
	2.1 Introduction	12
	2.1.1 Available Computerized Data Files	12
	2.1.2 Variations in State Computerized Data Files	13
	2.1.3 POPULATION File Layout and Format	13
	2.2 Creation of POPULATION File	13
	2.2.1 Screening and Elimination of Ineligible Bridges	14
	2.2.2 Matching of Bridge and Accident Records	14
	2.3 Definitions and Assumptions	17
	2.3.1 Single Structure, Undivided Bridges	18
	2.3.2 Twin-Structure Bridges	19
	2.3.3 Single-Structure, Divided Bridges	20
	2.4 General Bridge Characteristics	21
	2.4.1 Type of Roadway	21
	2.4.2 Type of Bridge	22
	2.4.3 Physical Characteristics of Bridges	22
	2.4.4 Traffic Characteristics of Bridges	23
	2.4.5 Summary of Bridge Characteristics	23
	2.5 Bridge Narrowness Characteristics	25
	2.5.1 Types of Bridges and Roadways	25
	2.5.2 Physical Characteristics of Bridges	26
	2.5.3 Traffic Characteristics of Bridges	28
	2.6 Bridge Accident Characteristics	28
	2.6.1 Accident Types	28
	2.6.2 Accident Severity	32
	2.7 Summary	36
III.	EXTENT OF NARROW BRIDGE ACCIDENT PROBLEM	40
	3.1 Introduction	40
	3.1.1 Accident Frequency	40
	3.1.2 Accident Rate	40
	3.1.3 Accident Severity	41
	3.2 Evaluation of the Total Bridge Problem	41
	3.3 Evaluation of Bridge Narrowness as Related to Accident Rates	43
	3.3.1 One-Lane Bridges	47
	3.3.2 Two-Lane Undivided Single Structures	49
	3.3.3 Four-Lane Undivided Single Structures	51
	3.3.4 Four-Lane Divided Single Structures	51
	3.3.5 Other Divided Single Structures	51
	3.3.6 Four-Lane Twin Structures	54
	3.3.7 Other Twin Structures	54

TABLE OF CONTENTS (Cont'd)

			Page
	3.4	Evaluation of Bridge Narrowness as Related to Accident Severity	54
		3.4.1 One-Lane Bridges	59
		3.4.2 Two-Lane Undivided Single Structures	59
		3.4.3 Four-Lane Undivided Single Structures	59
		3.4.4 Four-Lane Divided Single Structures	59
		3.4.5 Other Divided Single Structures	59
		3.4.6 Four-Lane Twin Structures	60
		3.4.7 Other Twin Structures	60
	3.5	Summary	60
IV.	ACCIDENT FILE		62
	4.1	Introduction	62
	4.2	Creation of ACCIDENT File	62
		4.2.1 Sampling Scheme	62
		4.2.2 Accident Investigations	64
		4.2.3 Accident Reconstructions	65
		4.2.4 ACCIDENT File Layout and Format	66
	4.3	General Accident Characteristics	66
		4.3.1 Accident Type	67
		4.3.2 Environmental Data	67
		4.3.3 General Vehicle Data	68
		4.3.4 General Occupant Data	69
	4.4	Specific Accident Characteristics	71
		4.4.1 Impact Sequence	71
		4.4.2 Encroachment Characteristics	73
		4.4.3 Impact Conditions	76
		4.4.4 Separation Conditions	81
		4.4.5 Subsequent Impacts	81
	4.5	Relationships to Injury Severity	83
		4.5.1 General Accident Characteristics	83
		4.5.2 First Barrier Impact	85
		4.5.3 Most Severe Impact	92
	4.6	Summary and Discussion	95
V.	SAMPLE FILE		101
	5.1	Introduction	101
	5.2	Creation of SAMPLE File	101
		5.2.1 Sampling Scheme	101
		5.2.2 Field Data Collection	102
		5.2.3 Data Processing	106
	5.3	Description of SAMPLE File	108
		5.3.1 Weighted Versus Unweighted Data	108
		5.3.2 General Bridge Characteristics	111
		5.3.3 Bridge Narrowness Characteristics	114
	5.4	Accident Rates and Severity	119
		5.4.1 Accident Frequency and Rate	120
		5.4.2 Accident Severity	124

TABLE OF CONTENTS (Cont'd)

		Page
	5.5 Bridge Accident Characteristics	129
	5.5.1 General Accident Characteristics	129
	5.5.2 Bridge and Approach Characteristics	132
	5.6 Summary	137
VI.	RELATIONSHIPS BETWEEN BRIDGE CHARACTERISTICS AND ACCIDENTS	142
	6.1 Introduction	142
	6.1.1 Statistical Analyses	142
	6.1.2 Independent Variables	143
	6.1.3 Dependent Variables	150
	6.2 Relationships for Individual Factors	153
	6.2.1 Bridge Characteristics	160
	6.2.2 Approach Characteristics	160
	6.2.3 Operational Characteristics	161
	6.2.4 Bridge Safety Index (BSI) Factors	162
	6.3 Hazardous vs. Non-Hazardous Bridges	165
	6.3.1 Accident Frequency	166
	6.3.2 Accident Severity	169
	6.3.3 Urban vs. Rural Bridges	169
	6.3.4 Narrow vs. Non-Narrow Bridges	169
	6.4 Accident Bridges	171
	6.4.1 Undivided Bridges With Accidents	174
	6.4.2 Divided Bridges With Accidents	175
	6.4.3 Urban Versus Rural Bridges	175
	6.4.4 Narrow vs. Non-Narrow Bridges	176
	6.5 Summary	177
	6.5.1 Individual Bridge Factors	177
	6.5.2 Hazardous vs. Non-Hazardous Bridges	178
	6.5.3 Accident Bridges	179
VII.	CONCLUSIONS AND RECOMMENDATIONS	181
	7.1 Findings and Conclusions	181
	7.1.1 General	181
	7.1.2 General Bridge Characteristics	182
	7.1.3 General Bridge Accident Characteristics	183
	7.1.4 Specific Bridge Accident Characteristics	184
	7.1.5 Extent of Narrow Bridge Accident Problem	186
	7.1.6 Relationships Between Individual Bridge Characteristics and Accident Measures	187
	7.1.7 Statistical Relationships Between Bridge Characteristics and Accident Measures	188
	7.2 Discussion and Recommendations	189
REFERENCES		195

LIST OF ILLUSTRATIONS

Figure		Page
1	PARTICIPATING STATES	9
2	MEAN ACCIDENT RATES AND RANK SCORES FOR ONE-LANE SINGLE STRUCTURES	48
3	MEAN ACCIDENT RATES FOR TWO-LANE UNDIVIDED SINGLE STRUCTURES	50
4	MEAN ACCIDENT RATES FOR FOUR-LANE UNDIVIDED SINGLE STRUCTURES	52
5	MEAN ACCIDENT RATES FOR FOUR-LANE DIVIDED SINGLE STRUCTURES	52
6	MEAN ACCIDENT RATES FOR OTHER (≠ 4-LANE) DIVIDED SINGLE STRUCTURES	53
7	MEAN ACCIDENT RATES FOR FOUR-LANE TWIN STRUCTURES	55
8	MEAN ACCIDENT RATES FOR OTHER (≠ 4-LANE) TWIN STRUCTURES	55
9	STUDY AREA FOR BRIDGE ACCIDENT INVESTIGATIONS	63
10	DISTRIBUTION OF VEHICLE DAMAGE BY DIRECTION OF FORCE FOR FIRST BARRIER IMPACT	70
11	DISTRIBUTION OF DEPARTURE ANGLES	74
12	DISTRIBUTION OF DEPARTURE SPEEDS	75
13	DISTRIBUTION OF IMPACT ANGLES FOR FIRST BARRIER IMPACT	77
14	DISTRIBUTION OF IMPACT SPEEDS FOR FIRST BARRIER IMPACT	78
15	DISTRIBUTION OF VELOCITY CHANGE FOR FIRST BARRIER IMPACT	80
16	RELATIONSHIP BETWEEN INJURY RATE AND IMPACT SPEED OF FIRST BARRIER IMPACT	89
17	RELATIONSHIP BETWEEN INJURY RATE AND IMPACT ANGLE OF FIRST BARRIER IMPACT	90
18	RELATIONSHIP BETWEEN INJURY RATE AND VELOCITY CHANGE OF FIRST BARRIER IMPACT	91

LIST OF TABLES

Table		Page
1	PERCENTAGES OF BRIDGE-RELATED ACCIDENTS	2
2	NUMBERS OF BRIDGES	2
3	FACTORS USED TO DETERMINE SIMPLIFIED BRIDGE SAFETY INDEX	6
4	LISTING OF SUBFILES FOR THE POPULATION, SAMPLE, AND ACCIDENT DATA FILES	11
5	SUMMARY OF SCREENING AND ELIMINATION PROCESS	15
6	KEY BRIDGE CHARACTERISTICS (AVERAGE VALUES) BY FUNCTIONAL CLASSIFICATION	24
7	KEY BRIDGE CHARACTERISTICS (AVERAGE VALUES) BY BRIDGE NARROWNESS STRATIFICATION	27
8	DISTRIBUTION OF SINGLE VEHICLE ACCIDENTS BY OBJECT STRUCK AND LANE STRATIFICATION	30
9	DISTRIBUTION OF MULTI-VEHICLE ACCIDENTS BY MANNER OF COLLISION AND LANE STRATIFICATION	31
10	DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY OBJECT STRUCK	34
11	DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY MANNER OF COLLISION	35
12	DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY LANE STRATIFICATION - TOTAL ACCIDENTS	37
13	COMPARISON OF AVERAGE AND BRIDGE-RELATED ACCIDENT RATES	42
14	TOTAL AND SINGLE VEHICLE ACCIDENT FREQUENCIES AND RATES BY FUNCTIONAL CLASSIFICATION	44
15	TOTAL ACCIDENT FREQUENCIES AND RATES BY BRIDGE NARROWNESS STRATA	45
16	SINGLE VEHICLE ACCIDENT FREQUENCIES AND RATES BY BRIDGE NARROWNESS STRATA	46
17	DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY BRIDGE NARROWNESS STRATA - TOTAL ACCIDENTS	56
18	DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY BRIDGE NARROWNESS STRATA - SINGLE VEHICLE ACCIDENTS	57
19	DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY BRIDGE NARROWNESS STRATA - MULTI-VEHICLE ACCIDENTS	58

LIST OF TABLES (Cont´d)

Table		Page
20	TOTAL NUMBER OF IMPACTS	72
21	LOCATION OF FIRST IMPACT	72
22	OBJECT CONTACTED IN FIRST IMPACT	72
23	DISTRIBUTION OF IMPACT ANGLES BY IMPACT SPEEDS FOR FIRST BARRIER IMPACT	79
24	BARRIER PERFORMANCE	82
25	SUBSEQUENT IMPACT	82
26	TOTAL NUMBER OF IMPACTS AND INJURY SEVERITY	84
27	DISTRIBUTION OF INJURY SEVERITY BY VEHICLE SIZE AND WEIGHT	86
28	ROLLOVER INVOLVEMENT AND INJURY SEVERITY	87
29	AVERAGE IMPACT SPEED AND ANGLE OF FIRST BARRIER IMPACT BY HIGHEST INJURY SEVERITY	87
30	DISTRIBUTION OF MOST SEVERE IMPACT	93
31	HIGHEST OCCUPANT INJURY SEVERITY BY OBJECT STRUCK - MOST SEVERE IMPACT	93
32	HIGHEST OCCUPANT INJURY SEVERITY BY IMPACT SPEED - MOST SEVERE IMPACT	94
33	HIGHEST OCCUPANT INJURY SEVERITY BY VELOCITY CHANGE - MOST SEVERE IMPACT	94
34	HIGHEST OCCUPANT INJURY SEVERITY BY VEHICLE DEFORMATION LOCATION - MOST SEVERE IMPACT	96
35	HIGHEST OCCUPANT INJURY SEVERITY BY DIRECTION OF FORCE - MOST SEVERE IMPACT	97
36	DISTRIBUTION OF BRIDGES BY STRATIFICATION SCHEME	103
37	PLANNED SAMPLE SIZE BY STRATIFICATION SCHEME	104
38	FINAL SAMPLE SIZES AND WEIGHTING FACTORS	107
39	COMPARISON OF SAMPLE FILE AND POPULATION FILE BRIDGE TYPES FOR DIVIDED HIGHWAYS	109

LIST OF TABLES (Cont'd)

Table		Page
40	COMPARISON OF SAMPLE FILE AND POPULATION FILE BRIDGE TYPES FOR UNDIVIDED HIGHWAYS	110
41	AVERAGE APPROACH AND BRIDGE VALUES	113
42	DISTRIBUTION OF SAMPLE BRIDGES BY NARROWNESS CATEGORY	115
43	SELECTED BRIDGE AND APPROACH CHARACTERISTICS BY NARROWNESS CATEGORY AND ACCIDENT OCCURRENCE	118
44	DISTRIBTUION OF BRIDGES WITH ACCIDENTS BY NARROWNESS CATEGORY	121
45	ACCIDENT FREQUENCIES AND RATES BY AVERAGE DAILY TRAFFIC	125
46	ACCIDENT SEVERITIES BY NARROWNESS CATEGORY	126
47	ACCIDENT SEVERITIES BY AVERAGE DAILY TRAFFIC	127
48	DISTRIBUTION OF INJURY SEVERITY BY FIRST HARMFUL EVENT	131
49	DISTRIBUTION OF FIRST HARMFUL EVENT BY NARROWNESS CATEGORY	133
50	DISTRIBUTION OF MANNER OF COLLISION BY NARROWNESS CATEGORY	134
51	DISTRIBUTION OF OBJECT STRUCK BY NARROWNESS CATEGORY	135
52	DISTRIBUTION OF FIRST HARMFUL EVENT BY AVERAGE DAILY TRAFFIC	138
53	LIST OF VARIABLES AND CORRESPONDING CODES	144
54	LIST OF INDEPENDENT VARIBLES	149
55	AVERAGE VALUES OF INDEPENDENT VARIABLES FOR NARROW VERSUS NON-NARROW BRIDGES	151
56	SUMMARY OF REGRESSION AND ANOVA RESULTS FOR UNDIVIDED BRIDGES	154
57	SUMMARY OF REGRESSION AND ANOVA RESULTS FOR DIVIDED BRIDGES	157
58	RESULTS OF DISCRIMINANT ANALYSIS ON ACCIDENT FREQUENCY FOR BRIDGE, APPROACH, OPERATIONAL, AND COUNTERMEASURE CHARACTERISTICS	163

LIST OF TABLES (Cont'd)

Table		Page
59	RESULTS OF DISCRIMINANT ANALYSIS ON ACCIDENT SEVERITY	164
60	HYPOTHETICAL EXAMPLE TO ILLUSTRATE THE APPLICATION OF THE DISCRIMINANT FUNCTION	168
61	SUMMARY OF REGRESSION RESULTS FOR BRIDGE, APPROACH, OPERATIONAL, AND COUNTERMEASURE CHARACTERISTICS ON UNDIVIDED BRIDGES WITH ACCIDENTS	172
62	SUMMARY OF REGRESSION RESULTS FOR BRIDGE, APPROACH, OPERATIONAL, AND COUNTERMEASURE CHARACTERISTICS ON DIVIDED BRIDGES WITH ACCIDENTS	173

CHAPTER I. INTRODUCTION AND RESEARCH APPROACH

1.1 Statement of the Problem

It is well documented that motor vehicle traffic accidents with fixed objects account for a disproportionate number of fatalities and injuries in the complete traffic accident problem. On a yearly, nationwide basis, approximately 12 percent of all accidents involve striking fixed objects,[1,2] and they account for almost 30 percent of all fatal crashes.[3]

Many of the objects struck adjacent to the roadways have involved bridge structures and approach guardrail systems. However, published accident summary statistics are not generally available to indicate the significance of these bridge-related collisions. Typical exceptions are References 4 and 5, which report bridge-related accident experience for the States of Virginia and Kentucky. Notable in these reports are the significant percentages of total accidents and fatalities for bridge-related collisions, as shown in Table 1. Of greater importance is the finding that the severity of bridge-related accidents is roughly twice that of the average accident.[2] While such summary statistics do not provide much of the data necessary to effectively analyze the specific problem, they do indicate that bridges represent a severe accident problem.

It is estimated that there are 564,000 bridges in the United States and that approximately one out of five or about 105,000 of them are structurally deficient or functionally obsolete.[6] From a survey by the National Association of Counties, the situation is even worse, as shown in Table 2.[7] The lower portion of this table is the information provided by FHWA in its seventh annual report to Congress (December, 1977). These figures represent decreases from those FHWA reported in its sixth annual report. The decreases do not mean bridges repaired but reflect federal-aid highway system realignment. It is estimated that the number of structurally deficient or functionally obsolete bridges is increasing at the rate of 2,000 bridges per year.[6] The 1977 cost to repair or replace the 105,000 deficient bridges was estimated at $25.1 billion.

In an overview of the hazards associated with narrow bridges, some mention should be made of the relationships of bridges that are deficient in width and those that are unsafe because of structural deficiencies. This relationship is important because, at many problem bridge sites, these

TABLE 1

PERCENTAGES OF BRIDGE-RELATED ACCIDENTS

State	Interstate/Parkway Highways		Primary/Secondary Highways	
	Percentage of All Accidents	Percentage of All Fatalities	Percentage of All Accidents	Percentage of All Fatalities
Virginia(4)	3.2	7.1	1.6	3.4
Kentucky(5)	7.6	17.2	2.9	3.8

TABLE 2(7)

NUMBERS OF BRIDGES

Off-System Bridges Under County Jurisdiction

Type	Number
Total number of off-system bridges	233,800
Number of structurally deficient bridges*	77,900
Number of functionally obsolete bridges**	88,900

On-System Bridges - FHWA

Type	Number
Total number of bridges on federal-aid	234,016
Number of structurally deficient bridges	6,912
Number of functionally obsolete bridges	26,603

* According to FHWA, a structurally deficient bridge is one which has been restricted to light traffic or closed.

** According to FHWA, a functionally obsolete bridge is one whose deck geometry, clearance, approach roadway alignment or load-carrying capacity can no longer safely service the system of which it is an integral part.

two deficiencies coexist because of the age of the bridges involved. As a direct result of the tragic collapse of the Silver Bridge at Point Pleasant, West Virginia, in December, 1967, which resulted in deaths of 43 persons, Congress established the Special Bridge Replacement Program under U.S.C. Title 23, Section 204, of the Federal Aid Highway Act of 1970. Although the major emphasis of this program was directed to structurally deficient bridges, there were also provisions for the replacement of functionally obsolete bridges, as defined in Table 2. This definition includes narrow bridges but does not specifically indicate the number that are classified as too narrow.(8) The use of available summary accident data does not permit a good estimate of what proportion of the bridge-related accidents occurred because of bridge narrowness. Subsequent studies have revealed that there may be as many as 60,000 bridges that are deficient in width.(9) In fact, the actual extent of the narrow bridge problem was not known at the initiation of this study and was included as one of the program objectives.

Severe narrow bridge accidents occurred in New Mexico in December, 1972, and in Texas in March, 1973. In the New Mexico case, a school bus and a tractor semi-trailer collided on a bridge 19 feet wide, resulting in deaths of 17 young people and two adults and injuries for 18 others, four serious. The Texas case also involved a bus and truck collision on a bridge 22 feet wide, in which 9 persons died, all but one of whom were burned to death by the ensuing fire that swept quickly through both vehicles. These tragedies brought about Congressional hearings and renewed emphasis in finding effective means for reducing bridge accidents.(10) As a result of this Congressional interest in the subject, the Texas Transportation Institute study was initiated.(11) The objectives of the research were to define the narrow bridge problem, appraise the effectiveness of corrective measures and develop guidelines for treatment. Field studies were conducted in Arizona, Maine, Minnesota, Missouri, New Mexico, Texas, and Virginia. More about this study will be discussed later.

As far back as 1941, investigators were concerned with bridge widths. A study reported by Walker in that year referred to bridge narrowness in terms of the effect on the driver as measured by the transverse or lateral positions of the vehicles as they approached and crossed the nine test bridges.(12) Narrow bridges caused drivers to alter their course transversely in order to obtain a feeling of security. Driver performance in terms of speed and lateral position has been used in a number of other studies concerned with narrow bridges. For example, a West Virginia study concluded that six-foot outside shoulders with curbs and eight-foot shoulders with guardrails on rural freeway bridges would not seriously affect the operational characteristics of vehicles as they crossed the bridge.(13,14) Driver performance relationships were also used in the TTI study(11) and found to be similar to those in the early Walker study.(12) Thus, while definitive driver performance-bridge relationships have been supported by various researchers, the conclusions relate to operational characteristics at the bridges. If these measurable characteristics are to be used as proxy measures to predict potentially hazardous bridges, they must have a known relationship with accidents.(15) To the authors knowledge, no such relationship has been developed. It has been concluded that the relationship between accidents and shoulders cannot be well defined with the present state-of-the-art.(14)

Obviously, the most desirable of narrow bridge treatment alternatives from the safety standpoint is to widen the bridge. From a long-term study designed to relate accident experience on the Interstate System to its various geometric design characteristics, it was concluded that increased minimum lateral clearance at bridges reduce accident rates and property damage costs.(16) However, because of the low frequency of bridge-related accidents, this alternative is not generally warranted from a cost-effectiveness standpoint. The TTI study lists the following 14 additional countermeasures:(11)

- Change approach grades
- Realign roadway
- Install smooth bridge rail
- Install approach guardrail
- Place edge lines
- Eliminate barrier stripe (centerline) on approaches and bridge where one-lane operation is necessary
- Place pavement transition markings
- Install narrow bridge signs
- Install stop or yield signs or signalization
- Install delineator markings for gross pavement discontinuities (lane drops) at the bridge

- Install advisory speed signs
- Reroute commercial vehicles
- Control access, extraneous development, distracting lights, or other roadside disturbances
- Install approach and bridge delineation.

In the TTI study, a ten-factor Bridge Safety Index (BSI) was developed as a basic tool for evaluating alternatives and setting priorities. These factors are shown in Table 3. Because of the lack of pertinent supportive data and the difficulty in estimating the effect of the various treatments on the BSI, except by very subjective judgments, an HP&R project was undertaken to field test and improve the index.(17) A description of the inspection and rating of the fifty-bridge sample and a summary of the data obtained in this study will follow in a later report.

Some of the treatments discussed in the TTI study were applied by the Texas Highway Department on a series of bridges on older, two-lane highways in Texas.(18) Eleven narrow bridges were safety treated by (1) placing metal beam guardrail over the existing bridge rail, (2) providing an adequate transition section between the approach guardrail and the bridge guardrail and (3) providing delineation of the restricted roadway width with edgelines, diagonal shoulder markings, raised ceramic jiggle bars, raised pavement markers, and post mounted delineators. A seventeen-month accident study conducted after these treatments were installed revealed the reduction in accidents to be highly significant. However, the experimental design was a simple before/after study with its inherent weaknesses.(15)

Despite the ongoing programs and policies that have been directed to the narrow bridge accident problem and the research that has been conducted relative to such programs, the narrow bridge problem remains. Much better accident statistics need to be developed by which the contribution of specific highway and traffic elements can be defined. Accident reduction warrants for various geometric and traffic conditions should be developed. For this purpose, a need exists to be able to determine the degrees of hazards of functionally deficient bridges and to predict the effectiveness of the various safety treatments.

1.2 Program Objectives and Scope

In general, the objectives of this study are to (1) define the narrow bridge accident problem, including significant accident contributory

TABLE 3

FACTORS USED TO DETERMINE SIMPLIFIED BRIDGE SAFETY INDEX

	BRIDGE EVALUATION FACTOR	FACTOR RATINGS				
		0	5	10	15	20
F_1	Clear Bridge Width (ft.)	$\leqq 14$	16	18	20	$\geqq 26$
F_2	$\frac{\text{Bridge Lane Width (ft.)}}{\text{Approach Lane Width (ft.)}}$	$\leqq 0.8$	0.9	1.0	1.1	$\geqq 1.2$
F_3	Guard Rail & Bridge Rail Structure	Use Nomogram in Figure 7 for F_3 Factor Rating				
		1	2	3	4	5
F_4	$\frac{\text{Approach Sight Distance (ft.)}}{\text{85\% Approach Speed (mph)}}$	$\leqq 5$	7	9	11	$\geqq 14$
F_5	$\frac{\text{100 + Tangent Distance to Curve (ft.)}}{\text{Degree of Curvature}}$	$\leqq 10$	60	100	200	$\geqq 300$
F_6	Grade Continuity (%) [$G_A + \lvert G_1 - G_2 \rvert$	10	8	6	4	$\geqq 2$
F_7	Shoulder Reduction (%)	100	75	50	25	0
F_8	Volume (AADT)/Capacity (VPD)	0.50	0.40	0.30	0.10	0.05
F_9	Traffic Mix	Wide Discontinuities	Non Uniform	Normal	Fairly Uniform	Uniform
F_{10}	Distractions and Roadside Activities	Continuous	Heavy	Moderate	Few	None

Source: Reference 17

factors, (2) appraise the effectiveness of selected corrective measures, and (3) develop cost-effective warrants for alternative safety treatments. The original specific objectives and scope of work were the following:

1. Identify the extent of the accident problem associated with narrow bridge sites.

2. Determine the relationship between the frequency and severity of motor vehicle accidents to narrow bridge structural condition, design, and the geometrics and condition of their approaches.

3. Determine the traffic operating characteristics of motor vehicles (including commercial truck combinations and buses) approaching and traversing narrow bridges.

4. Evaluate the accident reduction effectiveness of existing safety countermeasures applicable to the narrow bridge accident problem.

5. Develop accident reduction warrants applicable to narrow bridge problems.

This study is not to be limited to any specific road or street system or group of systems but is to consider narrow bridges on all road and street networks in the nation. In conducting the study, the aim should be directed to two basic areas. The first area of consideration is that along the Federal Aid Highway Systems (on and off the State Systems) where moderate and high traffic volumes permit substantial expenditures for safety. The second area that must be considered are those highway networks (low volume State and local roads and streets) where the best possible investments in the long run for the highest standards of safety and service may need to be compromised because of severe economic constraints.

After the first few months of work in the contract, developments occurred that defined major problem areas and suggested additions/ modifications in the methodology as originally specified. The original work statement called for the study of 20,000+ bridge accidents on all road systems. Further evaluations of the study design indicated that bridges with no accident experience should be included as control groups. It was thus recommended and agreed upon that bridges were the units for evaluation and not accidents. Also, traffic operating characteristics and county and local road systems were excluded from the study because of lack of information. Thus, only bridges on the State highway systems were included.

A critical literature review was conducted with a primary objective of identification and, to the extent possible, quantification of countermeasures, along with a study of methods that might be of value in formulating the cost-effectiveness algorithm and developing the countermeasure warrants. Several books, reports, and other documents were reviewed and evaluated for use. Some of the information was of value in establishing procedures for identification of hazardous locations, identification and typical construction details of countermeasure treatments, and procedures in cost-effectiveness methodology. However, the review was not productive in determining estimates of countermeasure effectiveness, and it was decided that most of this information would have to be retrieved from analyses of the data files generated in the study.

1.3 Research Approach

The sources of information for use in this study consisted of the bridge inventory and accident files, photologs, and various computerized and manual files of five participating States. These States included Arizona, Michigan, Montana, Texas, and Washington (see Figure 1). From this information, along with that obtained from in-depth accident investigations, the following three separate data files were created for the study:

1. Population master data file (POPULATION) - This file included all bridges that met the study criteria. After completion of a screening and elimination process, 11,880 bridges remained in the file. Only key bridge, roadway, and traffic data elements that were available from various computerized State data files were included. For each bridge, accident(s) occurring on the bridge itself and within the 500 feet approach areas for each of the four study years (1975-1978) were identified and entered into the file as individual accident cases.

   The purpose of this POPULATION file was to determine the extent of the narrow bridge accident problem and the associated accident frequencies, rates, and distributions. In addition, the file provided the basis for developing a sampling plan to select bridges for in-depth study.

2. Sample master data file (SAMPLE) - A sample of 2,099 bridges was selected from the POPULATION file for in-depth study. Of these, 110 bridges were dropped for various reasons so that the number of bridges in the SAMPLE file was reduced to 1,989. For each bridge in this SAMPLE file, all data elements from the POPULATION file were included plus detailed data on bridge and approach characteristics collected from the field.

   The purpose of this SAMPLE file was to determine the relationships of various physical and traffic characteristics to accident

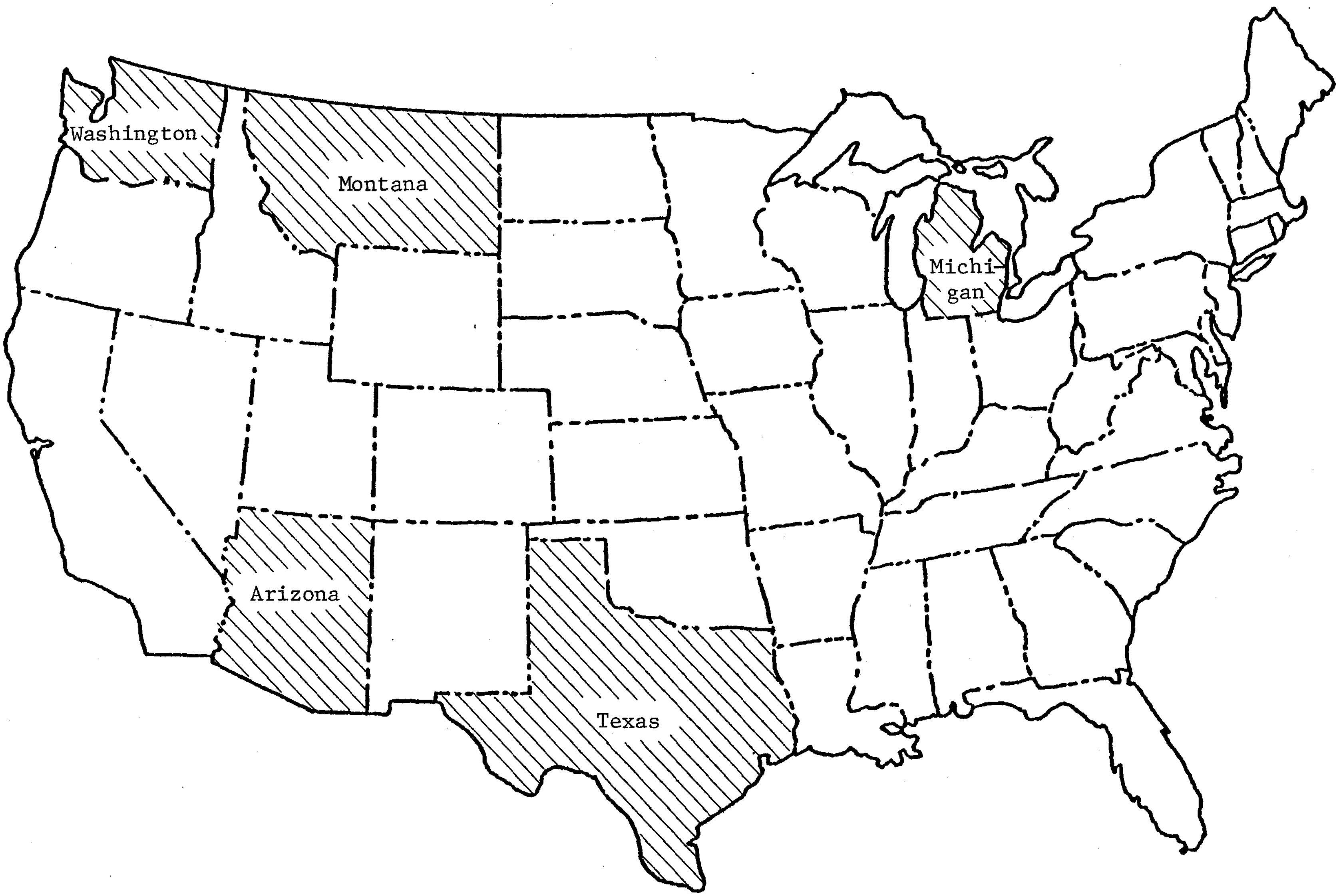


FIGURE 1. PARTICIPATING STATES

rates and severity as well as to evaluate countermeasure effectiveness. Subsequent analyses of the SAMPLE file revealed that definitive determinations of countermeasure effectiveness could not be made with the study design. Thus, on consultation with the contract manager, it was decided that incomplete development and cost-effectiveness evaluations of accident reduction warrants would not be included in this report.

3. Accident data file (ACCIDENT) - A third data file was also created, consisting of 124 bridge accidents studied in-depth. This ACCIDENT file was generated to provide more detailed insights on bridge accidents, especially those in which the first event in the collision sequence involved impacts to the bridge or to the guiding/protective device at the end of the bridge.

Each of these three data files contains various subfiles, listings of which are shown in Table 4. File formats and data element codes for the data files are provided in Appendix A for the POPULATION and SAMPLE files and in Appendix I for the ACCIDENT file.

Creation of the 11,880-bridge POPULATION file is described in Chapter II, and its use to establish the extent of the narrow bridge problem is presented in Chapter III. Chapter IV discusses the creation and analysis of the 124-bridge ACCIDENT file. Chapter V describes the creation of the SAMPLE file, containing data for 593 (1,088 weighted) two-lane divided bridges and 1,396 (6,574 weighted) two-lane undivided structures. Statistical analyses of the file to establish realtionships between bridge characteristics and accidents follow in Chapter VI. Finally, conclusions of the study and suggested future research are presented in Chapter VII.

TABLE 4

LISTING OF SUBFILES FOR THE POPULATION, SAMPLE, AND ACCIDENT DATA FILES

POPULATION FILE

1. Header File (HEADER)
   104 variables (HV)
   280 characters
   11,880 records

2. Trailer File (TRAILER)
   73 variables (TV)
   125 characters
   24,809 records

3. Combined Header/Trailer File (COMBINED)
   99 variables (48 HV; 2 CV; 49 TV)
   175 characters
   30,657 records (5,848 dummy records)

4. Front-End Program
   A. POPULATION Bridge Summary File (SUMMARY)
      78 variables (48 HV; 8 SV; 16 ASV; 6 ASVxxS)
      211 characters
      11,880 records
   B. Other Temporary Files (Unlabeled)
      72 variables (48 HV; 8 SV; 16 ASV)
      178 characters
      11,880 records

SAMPLE FILE

1. SAMPLE File (SAMPLE)
   155 variables (SAV)
   286 characters
   1,989 records

2. Combined SAMPLE/POPULATION File (SAMPOP)
   254 variables (155 SAV; 46 HV; 2 CV; 49 TV; 2 WV)
   463 characters
   7,988 records (940 dummy records)

3. Front-End Program
   A. SAMPLE Bridge Summary File (SAMSUM)
      225 variables (155 SAV; 46 HV; 2 WV; 16 ASV; 6 ASVxxS)
      489 characters
      1,989 records
   B. Other Temporary Files (Unlabeled)
      219 variables (155 SAV; 46 HV; 2 WV; 16 ASV)
      456 characters
      1,989 records

ACCIDENT FILE

1. ACCIDENT Card Image File
   26 cards/record
      Accident Form - 1 card
      Vehicle Form - 3 cards
      Driver Form - 1 card
      Occupant Form - 10 cards
      Inventory Data Elements Form - 7 cards
      Environmental Scene Form - 4 cards
   124 records

2. ACCIDENT SUMMARY File
   235 variables
   428 characters
   124 records

Variable ID Legends:

HV = Header	ASV = Accident Summary
TV = Trailer	ASVxxS = Accident Summary-Single Vehicle Accidents
CV = Control	SAV = Sample
SV = Selection	WV = Weight

CHAPTER II. POPULATION FILE

2.1 Introduction

To define the extent of the narrow bridge accident problem and the associated accident frequencies, rates, and distributions, a population master data file, or POPULATION file in short, was created. This file includes all bridges that meet the study criteria and contains key bridge, roadway, and accident data elements extracted from available computerized data files of the five study States (Arizona, Michigan, Montana, Texas, and Washington). This chapter discusses the development of the file and presents some descriptive statistics of its contents.

2.1.1 Available Computerized Data Files

The POPULATION file was created solely from available computerized State data files and excluded any manual data files or manual data collection. The availability of computerized data files varied among the five study States. However, as a minimum, two files were required from each State--the State bridge inventory file and the State accident record files for years 1975-1977. Since these two files did not always contain all of the information desired for inclusion in the POPULATION file, additional computerized State files, specifically State roadlog and traffic files, were used as supplements. A summary of the computerized data files available from the study States follows:

	Computerized Data Files			
	Bridge Inventory	Accident (1975-1977)	Roadlog	Traffic
Arizona	X	X	X	-
Michigan	X	X	-	-
Montana	X	X	X	X
Texas	X	X	X	X
Washington	X	X	X	X

X - Available

- - Not Available

Additionally, other supplemental files were used in some instances to provide necessary identifying links between data files to aid in the data processing.

2.1.2 Variations in State Computerized Data Files

Each State maintains its own data files by utilizing a file setup suitable to its own facilities and purposes. As a result, file data elements, codes, and formats vary considerably from State to State. In addition to file variations between States, many discrepancies and inconsistencies exist between data files within the same State since different data files are often prepared and maintained by different State agencies or offices within the same agency. One example of such variation of data files within a single State is the use of different location identification systems between bridge records and accident records. These variations between the States and within the States made utilization and comparison of data from the study States impossible unless the data were transformed into a common format with common codes for the file records. Thus, in order to attain uniformity of data, a series of transformations in data definitions, codes, and formats were necessary in the creation of the POPULATION file.

2.1.3 POPULATION File Layout and Format

The POPULATION file consists of two types of records: Bridge (Header) records containing information pertinent to each bridge and its approaches, and Accident (Trailer) records describing individual accidents identified as occurring on the bridges or within the approaches. A Header-Trailer format was chosen because the number of accidents identified as occurring on a particular bridge or its approaches varies considerably among bridges, from no accidents to over a hundred accidents. A single record format would be extremely lengthy and unwieldy for processing. Thus, a Header-Trailer type of format was used so that multiple Trailer (accident) records could be identified with a single Header (bridge) record.

For analysis purposes, various subfiles were created within the POPULATION file. Details of the subfile layouts and data element format and codes are contained in Appendix A.

2.2 Creation of POPULATION File

The POPULATION file was created in a step-by-step process, the details of which are described in Appendix B. Basically, bridge and accident records were created separately by extracting pertinent data from the State computerized data files. The accident records were then matched to the corresponding bridge records according to milepoints so as to identify accidents occurring on the bridges or within bridge approach areas. Highlights of the file creation process and items of interest are briefly presented in the following subsections.

2.2.1 Screening and Elimination of Ineligible Bridges

The State bridge inventory files contain information on every structure under State jurisdictions and some even include structures not on State highway systems. An extensive screening and elimination process was carried out to select only those bridges that met the study criteria for inclusion in the POPULATION file. Table 5 summarizes the results of the screening and elimination process and the various reasons for which structures were eliminated from further consideration.

Overall, 31,652 of the total 43,532 bridges were eliminated, leaving only 11,880 bridges in the POPULATION file. Detailed explanations of individual screening and elimination criteria were presented in Appendix B. The bridges that were selected for the POPULATION file can be characterized as follows:

1. The bridges are on State highway systems.
2. The bridges are overpass structures carrying main-line vehicular traffic, excluding culverts and second structures of twin structures.
3. There are no traffic control signals on the bridges or within the approach areas to the bridges.
4. All key data elements on the bridges are known, especially location identifiers to permit matching of accidents to the bridges.

It should be emphasized that the study findings will only apply to bridges meeting these study criteria. Any extrapolation or extension of the study results to bridges outside of the study criteria should be viewed with extreme caution.

2.2.2 Matching of Bridge and Accident Records

With the exception of Texas, there are no provisions in the State accident files to identify the location of an accident in relation to a bridge and its approaches. Even for Texas, an accident is coded as bridge related only if the reporting officer considers the presence of the bridge as a contributory factor to the accident. The only means of identifying accidents to the corresponding bridges and their approaches is by matching

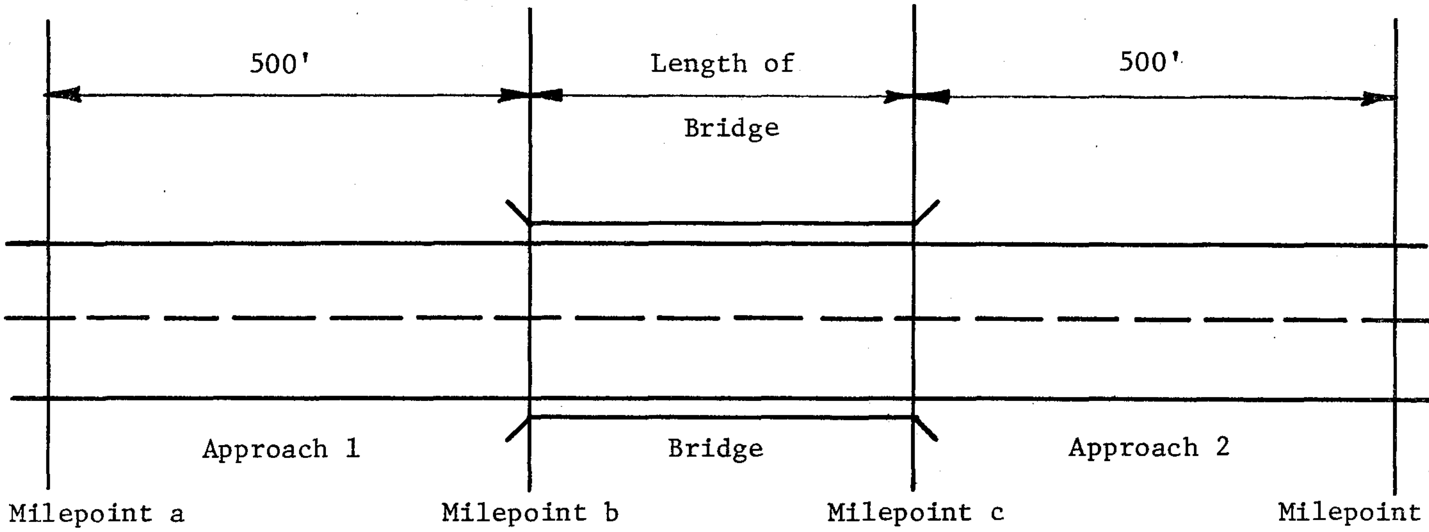
TABLE 5

SUMMARY OF SCREENING AND ELIMINATION PROCESS

	Arizona	Michigan	Montana	Texas	Washington	Total
Initial Number of Bridges in State Bridge Inventory File	4,933	4,218	3,406	28,135	2,840	43,532
Number of Bridges Eliminated						
Basic Eligibility Criteria (Including Unknown Location Identifiers)	1,834	1,744	1,142	5,448	748	10,956
Control Section or Route Breaks	2	19	27	197	31	276
Twin Structures	480	585	282	1,190	435	2,972
Overlapping Milepoints	156	87	129	1,342	66	1,780
Traffic Control Signal	11	216	4	299	95	625
Culverts	1,830	47	2	10,472	3	12,354
Revised Screening Criteria	91	418	137	1,939	144	2,729
TOTAL ELIMINATED	4,404	3,116	1.723	20,887	1,522	31,652
Number of Bridges Retained in POPULATION File	529	1,102	1,683	7,248	1,318	11,880

of the milepoints.

Each bridge and its approaches are defined by four milepoints, as illustrated in the diagram below:



The location of an accident in relation to the bridge is simply a matter of comparing the accident milepoint to the four bridge milepoints. For example, if the milepoint of an accident is between milepoints a and b, the accident is located in Approach 1 to the bridge.

This milepoint matching process seems straightforward enough in theory. However, there is a lack of accuracy in the reporting of accident locations, and this poses a major problem to the milepoint matching between bridges and accidents. First, bridge milepoints are recorded to the nearest 0.001 mile while accident locations are reported only to the nearest 0.1 mile. On considering that 75 percent of the study bridges are less than 200 feet (0.038 mile) in length, it is evident that it would not be possible to pinpoint an accident as to whether it occurred on the bridge or not. This problem is partially alleviated by combining the two 500 feet approach areas with the bridge itself in the milepoint matching process. Again using a bridge length of 200 feet, the combined length of the bridge and its approach is now 1,200 feet or 0.227 mile. Thus, a reasonable level of accuracy may be expected from the milepoint matching process.

Furthermore, the accuracy of the accident milepoints is itself a problem area. For instance, it has been found in this and other studies that there is an apparent trend of overreporting accident locations at the half or whole milepoints. However, such problems are inherent in the data itself and cannot be alleviated.

In summary, there are many problems associated with this milepoint matching between bridges and accidents, the most critical of which is the general inability to pinpoint the exact location of an accident in relation to the bridge itself. It should therefore be noted that no distinction is made between accidents occurring on the bridges and those in approach areas in the data analyses.

2.3 Definitions and Assumptions

Definitions of the terms used in developing and analyzing the POPULATION file are given in this section. Also, because of the nature of the computerized State files, necessary assumptions made in the development and analysis are discussed.

As delineated in the Work Statement, bridges were categorized according to various degrees of narrowness, including the non-narrow category. The stated narrowness definitions are as follows:

A. Narrow Bridge Definitions:

(1) One-lane, 18 feet or less in width.

(2) Two-lane, 24 feet or less in width.

(3) Total approach width greater than total bridge width (curb-to-curb) and bridge shoulder width is less than 50 percent of approach roadway shoulder width (i.e., > 50 percent shoulder reduction).

(4) Total approach width greater than total bridge width and the bridge shoulder width is 50 percent or more (but less than) approach roadway shoulder width (i.e., 1-50 percent shoulder reduction).

B. Non-Narrow Bridge Definitions:

(1) One-lane, more than 18 feet in width.

(2) Total bridge width equal to or greater than total approach roadway width.

Provided all of the various widths (bridge widths, bridge and approach shoulder widths, etc.) were known, the bridges could be classified into the above categories without complications. However, bridge and approach roadway shoulder widths were not available from the files. Consequently, calculations to identify less than or greater than 50 percent shoulder reductions could not be directly performed and alternative criteria for identifying 50 percent shoulder reduction had to be established. These alternative criteria and the underlying assumptions are presented in the following paragraphs, subdivided according to the bridge types:

(1) Single-structure, undivided bridges.

(2) Twin-structure bridges.

(3) Single-structure, divided bridges.

2.3.1 Single Structure, Undivided Bridges

In order to establish criteria for determining percent shoulder reduction, certain assumptions about the bridge and approach roadway were made. These assumptions were:

(1) The number of lanes and lane widths are equal for the approach roadway and bridge.

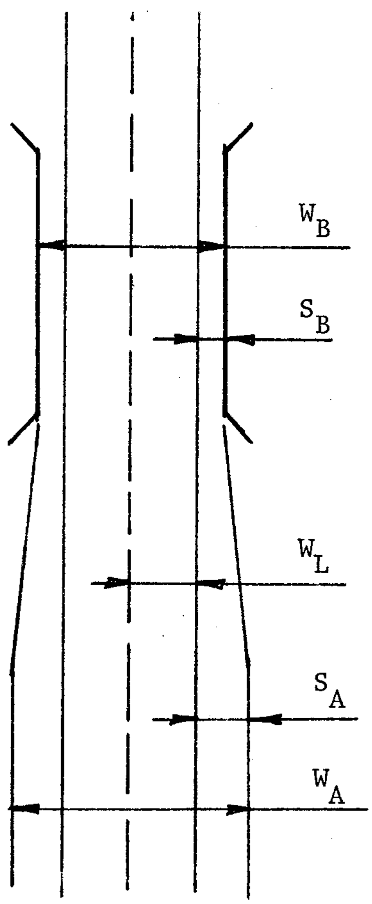
(2) The lane widths are assumed for each State based on the State's design standards. Specifically, the lane width assumptions for the States are:

Arizona & Montana - 12′ lane widths

Texas - 10′ lane widths for collectors and local roads
- 12′ lane widths for interstates and arterials

Michigan & Washington - 11′ lane widths for collectors and local roads
- 12′ lane widths for interstates and arterials.

The assumptions and accompanying calculations are illustrated in the diagram below.



W_B = Bridge curb-to-curb width

W_A = Approach roadway width, including shoulders

W_L = Lane width (assumed)

N = Number of lanes

S_B = Bridge shoulder width

$$= \frac{(W_B - N \cdot W_L)}{2}$$

S_A = Approach shoulder width

$$= \frac{(W_A - N \cdot W_L)}{2}$$

Percent Shoulder Reduction

$$= \frac{(S_A - S_B)}{S_A} \times 100\%$$

2.3.2 Twin-Structure Bridges

Criteria for determining percent shoulder reduction on twin-structure bridges included assumptions on approach shoulder widths because the approach roadway widths for divided roadways included the median widths, which were unknown, and shoulder widths could not be directly determined. The basic assumptions made were:

(1) The number of lanes and lane widths are equal for the approach roadway and bridge.

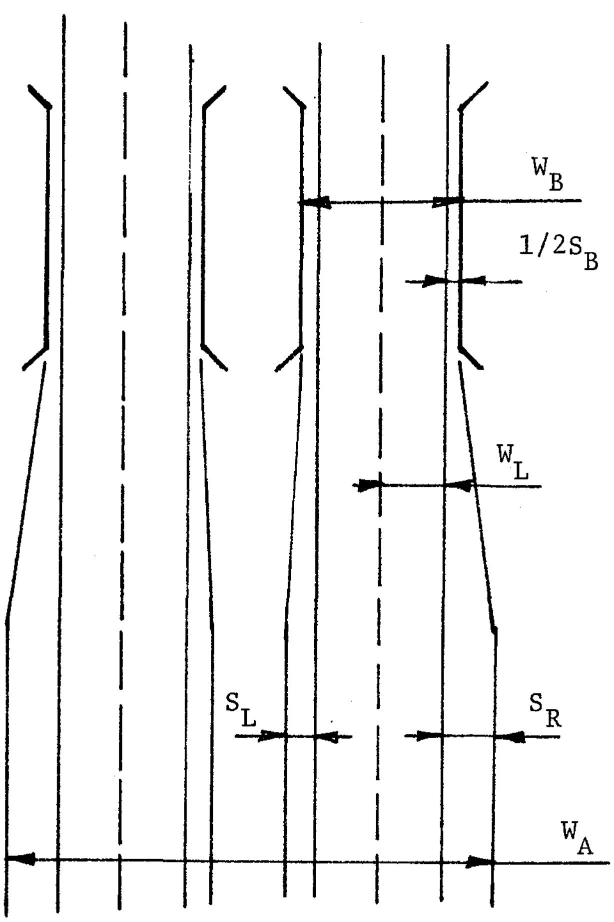
(2) Based on design standards for the five States, 12-foot lane widths are assumed for all of the States.

(3) Approach shoulder widths are assumed for each of the five States, again based upon the State's design standards. The assumed shoulder widths for the States are:

Arizona - 10' right shoulders; 5' left shoulders

Michigan, Montana, Texas, & Washington - 10' right shoulders; 4' left shoulders.

The assumptions and accompanying calculations are illustrated in the diagram below.



W_B = Bridge curb-to-curb width

W_A = Approach roadway width (as illustrated)

W_L = Lane width (assumed to be 12')

N = Number of lanes

S_B = Bridge shoulder width

$$= \frac{(W_B - N \cdot W_L)}{2} = \frac{(W_B - 12N)}{2}$$

S_L = Left approach shoulder width (assumed to be 4')

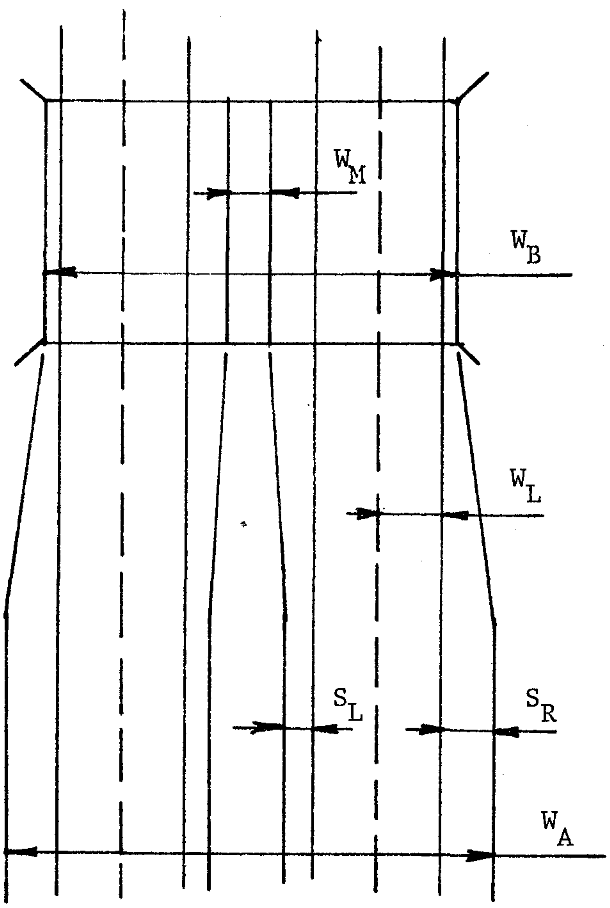
S_R = Right approach shoulder width (assumed to be 10')

Percent Shoulder Reduction

$$= \frac{(S_L + S_R)/2 - S_B}{(S_L + S_R)/2} \times 100\% = \frac{(7 - S_B)}{7} \times 100\%$$

2.3.3 Single-Structure, Divided Bridges

For divided single structures, percent shoulder reduction was calculated in a manner similar to the procedure used for twin-structure bridges. Assumptions were the same as those for twin-structure bridges with an additional assumption of the median width on the bridge. The bridge median width must be assumed in order to calculate bridge shoulder width. Based on the best available information from the States regarding median widths, the median was assumed to be 4 feet wide for all of the States. The assumptions and accompanying calculations are illustrated in the diagram below.



W_B = Bridge curb-to-curb (as illustrated)

W_A = Approach roadway width (as illustrated)

W_L = Lane width (assumed to be 12′)

W_M = Median width (assumed to be 4′)

N = Number of lanes

S_B = Bridge shoulder width

$$= \frac{(W_B - N \cdot W_L - W_M)}{2} = \frac{(W_B - 12N - 4)}{2}$$

S_L = Left approach shoulder width (assumed to be 4′)

S_R = Right approach shoulder width (assumed to be 10′)

Percent Shoulder Reduction

$$= \frac{(S_L + S_R)/2 - S_B}{(S_L + S_R)/2} \times 100\% = \frac{(7 - S_B)}{7} \times 100\%$$

As shown, the extent of shoulder reduction on the bridges could not be determined directly from the data available, and it became necessary to make certain assumptions and then calculate the percent shoulder reduction accordingly. These assumptions, especially regarding approach shoulder widths, lane widths, and median widths, were based on the design standards most appropriate for the types of roadway under consideration. It is inevitable that some roadways and bridges were not constructed according to the current design standards, and this will introduce some errors into the classification of bridges by degree of narrowness. However, the amount of error introduced would likely be minor and should not effect the validity of the results.

2.4 General Bridge Characteristics

This section describes some of the general bridge characteristics for the 11,880 bridges of the POPULATION file. Only salient features are noted here. Tables showing more complete descriptive statistics are included in Appendix C. Also, it should again be emphasized that the results apply only to the bridges as defined by the study criteria. Any extrapolation or extension of the results to bridges outside of the study criteria should be viewed with extreme caution.

2.4.1 Type of Roadway

Highway types on which the bridges are located by study States are shown in Tables A.1 and A.2 Since only bridges on State highway systems are included for the study, it is not surprising to see that over 90 percent of the bridges are in rural areas. Nearly 10 percent of the bridges are on interstate highways with another 43.6 percent on arterial highways. Rural collectors alone account for 46.4 percent of the study bridges. Also, over 10 percent of the bridges are on non-federal-aid State highways while the remaining bridges are on interstate highways or federal-aid primary or secondary roadways.

As shown in Tables A.3 and A.4, there are very few one-lane bridges on State highway systems. Single undivided structures on 2-lane highways account for 81.7 percent of the bridges, 95.6 percent of which are on rural arterials or collectors. Two-lane twin structures on 4-lane divided highways account for another 12.1 percent of the study bridges, two-thirds of which are on the interstate highways.

2.4.2 Type of Bridge

Tables A.5 through A.8 indicate the construction features for the bridges. Note that these construction features apply only to the main spans of the bridges, which may or may not be the same as those for the approach spans. As expected, the majority of the bridges are built of steel or concrete (90.4%) with slab, beam, or girder type construction (96.3%). Noteworthy is the large percentage (47.7%) of timber bridges in Montana. The predominant travelway is the deck type of construction (96.9%) with asphalt or concrete pavements (98.0%).

2.4.3 Physical Characteristics of Bridges

Tables A.9 through A.11 summarize the general physical dimensions of the bridges. The majority of the bridges are shorter than 200 feet in length (75.2%) with an average of 176 feet. This percentage increases to 86.5 percent for bridges up to 300 feet in length. Bridges with curb-to-curb (or rail-to-rail if no curbs are present) widths between 21 and 30 feet comprise 53.2 percent of the total, reflecting the predominance of 2-lane bridges. Also, 11.1 percent of the bridges have curb-to-curb widths of 21 feet or less. Sidewalks, most of which are less than 6 feet wide, are present on only a small fraction of the bridges (9.8%) .

Tables A.12 and A.13 show the ages and estimated remaining lives of the bridges. It is of interest to note that while 67.2 percent of the bridges were built or rebuilt after 1950, less than 3 percent were built/rebuilt during the three-year study period of 1975-1977, suggesting a slowdown in the construction or reconstruction of bridges. However, 55.9 percent of the bridges have estimated service lives of less than 20 years with 20.5 percent less than 10 years.

Bridge conditions and appraisals are indicated in Tables A.14 and A.15. The bridge deck and approach roadway conditions are rated as acceptable or good except for a few of the bridges. The percentage of bridges appraised as poor structurally is somewhat higher, but still rather small (3.1%). However, almost 16 percent of the bridges are rated poor on their deck geometry. Also, only 15.0 percent of the bridges have guardrail/bridge rail safety features that meet all current standards, while 40.9 percent of the bridges do not meet any of the current standards.

Again, it should be borne in mind that the bridges included in this study are confined to only those on the State highway systems, and it may reasonably be expected that their conditions and appraisals are better than those on non-State highway systems, such as local roads and city streets.

2.4.4 Traffic Characteristics of Bridges

The distributions of bridges by ADT stratifications are shown in Tables A.16 through A.19. Two different ADT classifications are used--one as specified in the original Work Statement (I) and the other as used in the National Highway Inventory and Performance Study (II). These classifications are as follow:

Structure Type	ADT Stratification I	ADT Stratification II
Single Structure, 1-3 Lanes	1-399 400-2,999 ≥ 3,000	1-99 100-399 400-999 1,000-3,999 ≥ 4,000
Single Structure, ≥ 4 Lanes or Twin Structures, ≥ 2 Lanes	1-4,999 5,000-19,999 ≥ 20,000	1-999 1,000-3,999 4,000-7,999 8,000-24,999 ≥ 25,000

For single structures with one to three lanes, the majority (53.1%) of the bridges have ADT of less than 100 vehicles, 3.6 percent of which have less than 1,000 ADT, and only 11.1 percent of the bridges have ADT of at least 4,000 vehicles. For multi-lane (≥ 4) single structures and twin structures, slightly over half (50.8%) of the bridges have ADT of 8,000 vehicles and more, while 22.3 percent of the bridges have less than 4,000 ADT. The ADT distributions for individual States reflect their urban or rural nature with Montana being the most rural of the five study States.

The distribution of ADT stratifications by functional classification of the roadways on which the bridges are located shows the expected patterns of higher ADTs in urban areas and higher classes of highways.

2.4.5 Summary of Bridge Characteristics

Table 6 summarizes the key bridge characteristics by functional classification. The values shown are average values. Urban bridges are longer and wider than their rural counterparts and have higher traffic

TABLE 6

KEY BRIDGE CHARACTERISTICS (AVERAGE VALUES) BY FUNCTIONAL CLASSIFICATION

Functional Classification	No. Bridges	Length(ft)	Curb-to-Curb Width(ft)	Approach Width(ft)	ADT	% Truck	% Shoulder Reduction	Remaining Life	Year Built/ Rebuilt
Urban Interstate	323	243.7	51.2	68.8	30,791	8.0	24.4	46	63
Urban Major Arterial	622	238.0	44.8	46.6	13,910	6.2	35.2	34	57
Urban Minor Arterial	206	183.7	33.8	36.0	5,390	6.3	44.3	23	55
Urban Collector	26	161.4	31.2	35.0	6,275	5.7	50.7	18	50
URBAN TOTAL	1,177	228.4	44.3	51.5	16,883	6.9	34.2	35	58
Rural Interstate	839	218.3	40.2	57.0	8,280	15.6	15.0	41	65
Rural Major Arterial	2,109	199.9	33.9	37.5	3,843	13.9	36.4	25	53
Rural Minor Arterial	2,246	175.5	31.2	34.5	1,989	11.0	45.5	24	50
Rural Collector	5,509	149.5	25.7	28.0	836	10.5	68.6	21	53
RURAL TOTAL	10,703	170.3	29.6	33.5	2,254	11.7	53.2	23	54
GRAND TOTAL	11,880	176.0	31.0	35.3	3,703	11.2	51.3	25	54

volumes but lower percentage of trucks. With the exception of interstate highways, rural bridges are narrower with greater percentage of shoulder reduction. Also, urban bridges are newer with longer remaining life.

As for the highway types, the interstate bridges are the largest, widest, and newest with the highest ADT and percentage of trucks, followed by major arterials, minor arterials, and collectors.

Overall, the averge length of an urban bridge is 228.4 feet with an average curb-to-curb width of 44.3 feet. The average approach roadway width is 51.5 feet for an average shoulder reduction of 34.2 percent. The average traffic volume is only 16,883 vehicles per day with a traffic mix of 6.9 percent trucks. In comparison, a rural bridge averages 170.3 feet long and 29.6 feet wide. The average approach roadway width is 33.5 feet for an average shoulder reduction of 53.2 percent. A rural bridge averages only 2,254 vehicles per day, 11.7 percent of which are trucks.

2.5 Bridge Narrowness Characteristics

With the assumptions discussed in Section 2.3, descriptive statistics were generated concerning the narrowness of the 11,880 bridges in the POPULATION file. Statistical tables are included in Appendix C. Salient features from these tables follow. The assumptions made in determining bridge narrowness should be borne in mind while reviewing the data and results contained in this section.

2.5.1 Types of Bridges and Roadways

The breakdown of bridges by narrowness stratification is shown by State in Table A.20 and by functional classification in Table A.21. For one-lane bridges, 85.2 percent (75 out of 88) are narrow with widths of 18 feet or less. For two-lane undivided single structures, 43.3 percent (4,199 out of 9,701) have widths of 24 feet or less, 68.1 percent (2,858 out of 4,199) of which have the bridge widths less than the approach roadway widths. Of the 5,502 two-lane undivided single structures with widths greater than 24 feet, 1275 (23.2%) have greater than 50 percent shoulder reduction and 1399 (25.4%) have 1-50 percent shoulder reduction. Overall, only 29.2 percent (2,828 out of 9,701) of two-lane undivided single structures can be classified as non-narrow according to the narrowness definitions used in the study. For four-lane undivided single structures, only 86 bridges out of 274 (32.1%) have any reduction in shoulder width and thus are termed as narrow.

For divided single structures, the percentages of narrow bridges are 83.9 (146 out of 174) for four-lane roadways and 49.5 (47 out of 95) for roadways with more than four lanes.

The majority (97.7%) of two-lane twin structures are more than 24 feet in width and over 60 percent (868 out of 1,440) of the bridges are non-narrow with no shoulder reductions. The percentage of non-narrow bridges increases to 70.4 percent (76 out of 108) for multi-lane twin structures. Overall, 71.9 percent of single structures are narrow, while that for twin structures is only 39 percent.

Narrow bridges are more prevalent in rural areas (67.4%) than in urban areas (52.8%) with the exception of interstate highways (36.2% rural versus 46.1% urban). Rural collectors have the highest percentage of narrow bridges (78.6%) while rural interstates have the lowest (36.2%). Also, the percentage of narrow bridges decreases with higher class of roadway.

2.5.2 Physical Characteristics of Bridges

Table 7 summarizes key bridge characteristics by the bridge narrowness strata. With a few exceptions, non-narrow bridges are generally shorter, wider, and newer and have lower ADTs than the narrow bridges as defined in the study. One major observation is the vast differences between two-lane undivided single structures with curb-to-curb widths of 24 feet or less and those greater than 24 feet in width. Bridges with widths of 24 feet or less are shorter in length and narrower in the approach roadway width with less than half of the traffic volume as compared to bridges with widths of greater than 24 feet.

Another major observation is that for undivided bridges where the bridge narrowness is determined by comparing the bridge curb-to-curb width to the approach roadway width,* non-narrow bridges have smaller approach roadway widths than the narrow bridges. This indicates that the absence or presence of shoulders on the approach roadway plays an important role in whether a bridge is defined as narrow or non-narrow.** This hypothesis was later verified with information from the SAMPLE file.

---

* For divided bridges, only the bridge curb-to-curb width is used in the determination of narrowness since the approach width includes the median width.

** Approach roadway width is defined as the combined width of the roadway itself and the shoulders so that if the roadway has no shoulder, the approach roadway width will essentially be the same as the roadway width. Hence, bridges on roadways with no approach shoulders are usually categorized as non-narrow bridges.

TABLE 7

KEY BRIDGE CHARACTERISTICS (AVERAGE VALUES) BY BRIDGE NARROWNESS STRATIFICATION

Bridge Narrowness Strata					No. of Bridges	Length(ft)	Curb-to-Curb Width(ft)	Approach Width(ft)	ADT	% Truck	% Shoulder Reduction	Remaining Life	Year Built/ Rebuilt
		No. Lanes	Bridge Width	Shoulder Reduction									
Single Structures	Undivided	1	≤18'	-	75	115.9	14.8	20.8	270	7.1	-	9	25
			>18'	-	13	48.2	19.6	20.8	455	6.8	-	16	22
		2	≤18', <Approach	-	77	159.2	17.3	25.1	512	9.6	-	10	31
			<18', ≥Approach	-	17	86.5	17.6	17.2	297	7.1	-	17	43
			18'-20', <Approach	-	700	118.7	19.8	25.9	640	10.8	-	15	46
			18'-20', ≥Approach	-	286	104.0	19.8	18.9	408	11.9	-	19	49
			20'-22', <Approach	-	386	160.2	21.5	27.4	1015	11.6	-	13	42
			20'-22', ≥Approach	-	135	132.4	21.4	19.5	615	10.0	-	17	44
			22'-24', <Approach	-	1695	161.9	23.7	29.9	1162	11.9	-	19	48
			22'-24', ≥Approach	-	903	143.4	23.9	21.8	731	12.5	-	18	51
			>24'	>50%	1275	275.7	27.5	38.8	3005	11.9	72.3	26	53
			>24'	1-50%	1399	157.9	31.9	35.7	2240	9.4	30.2	26	54
			>24'	None	2828	149.6	35.3	32.5	2219	11.3	0	26	59
		4	N/A	>50%	55	231.8	46.4	57.6	10673	6.1	91.8	25	50
				1-50%	31	177.4	54.0	57.1	7670	10.9	30.6	29	61
				None	188	186.4	51.6	48.9	7999	7.4	0	27	60
	Divided	4	N/A	>50%	81	362.9	56.7	66.4	14284	8.7	82.5	29	56
				1-50%	65	195.7	71.6	73.1	11795	10.7	30.3	33	61
				None	28	230.9	84.6	79.8	13570	13.3	0	41	67
		Other	N/A	>50%	27	438.4	78.0	82.6	47248	5.6	78.2	39	62
				1-50%	20	240.4	82.2	74.2	25912	3.3	29.1	49	65
				None	48	198.5	104.5	94.7	35508	6.7	0	43	65
Twin Structures	Divided	2	<24'	-	33	531.7	23.0	45.8	7913	11.1	-	14	36
			>24'	>50%	311	334.5	28.5	50.5	14185	12.8	68.4	34	58
			>24'	1-50%	228	233.9	35.9	48.2	10746	9.1	17.9	39	63
			>24'	None	868	168.0	40.5	50.2	8613	13.4	0	44	65
		Other	N/A	>50%	16	232.0	52.2	98.8	49204	10.0	75.1	51	63
				1-50%	16	457.4	55.8	93.5	45916	6.4	28.9	55	62
				None	76	211.4	63.3	96.1	36582	7.6	0	54	68
TOTAL					11880	176.0	31.0	35.3	3703	11.2	51.3	25	54

2.5.3 Traffic Characteristics of Bridges

Tables A.22 and A.23 show the distribution of the bridges by ADT, grouped according to stratification specified in the Work Statement (I) and in the National Highway Inventory and Performance Study (II), respectively. As expected, ADT increases with larger number of lanes, greater curb-to-curb width, and from undivided to divided structures. Some of the bridge narrowness and ADT stratification combinations have very few bridges and eventually caused some minor problems when selecting bridges for more in-depth study in the SAMPLE file.

2.6 Bridge Accident Characteristics

The POPULATION file contains a total of 24,809 accidents that occurred on the 11,880 bridges during the study period of 1975-77. This section discusses the characteristics of these accidents. Statistical tables are included in Appendix D. Salient features from these tables follow.

It should be emphasized that these 24,809 bridge accidents include both accidents occurring on the bridges and their approaches. No attempt was made to distinguish between accidents that occurred on the bridges and those in the approaches since the milepoint matching process, as described under subsection 2.2.3, does not have the needed degree of accuracy for such distinction. Also, it is not possible to determine from the accident records if the presence of the bridge was a contributory factor to an accident. Thus, all accidents that occurred on the bridges and their approaches are included in the analysis.

2.6.1 Accident Types

Table A.24 shows the distribution of accident types by functional classification. Of the 24,809 accidents, 10,815 (43.6%) were single vehicle accidents that involved fixed and other objects as well as non-collision types such as rollovers; 11,428 (46.1%) were multi-vehicle accidents involving two or more vehicles colliding with each other; and the remaining 2,566 (10.3%) accidents were grouped under the "other" category including such accident types as collisions with parked vehicles, pedestrians, animals, etc. Multi-vehicle accidents were predominant on urban bridges (60.5%) and single vehicle accidents on rural bridges (51.9%). Interstate bridges had a slightly higher percentage of single vehicle accidents and a lower percentage of multi-vehicle accidents than the other functional classes.

For single vehicle accidents, the distribution of object struck by functional classification is shown as Table A.25. Guardrail/median barrier is the most frequently struck object (24.5%), followed closely by bridge rail (21.2%). The near-equality would suggest that railing countermeasures should include combined retrofits of the guardrail and bridge rail systems, a conclusion that was also drawn in Reference 18. Bridge end/pier accounted for 6.6 percent of the single vehicle accidents. The more widespread use of guardrails and median barriers on urban highways and interstate highways is evident with their higher accident involvement on these highway types. This is also reflected by the lower incidence of collisions with bridge ends or piers. Also, the interstate highways have fewer roadside objects (other than barrier systems) and, consequently, lower percentages of accidents involving roadside objects.

Table A.26 shows the distribution of multi-vehicle accidents by manner of collision for the various functional classes. Interstates and major arterials have relatively more rear-end and sideswipe-same direction collisions but fewer head-on, sideswipe-opposite direction and angle impacts than minor arterials and collectors. Overall, rear-end collisions are the most frequent (35.0%), followed by angle collisions (14.2%) and sideswipes in the same direction (12.7%).

Table A.27 illustrates the distribution of accident types by lane stratification. Single vehicle accidents are the predominant accident type for one-lane (73.5%) and two-lane (46.8%) single structures and for four-lane twin structures (53.8%), while multi-vehicle accidents are the overwhelming majority on the other types of structures.

The distribution of single vehicle accidents by object struck for the various lane strata is shown in Table 8. Bridge rail (24.4%) and bridge end (8.7%) accidents show the highest percentage on two-lane undivided single structures and the lowest on divided single structures with more than four lanes. Guardrail/median barrier is the predominant object struck on divided single structures and twin structures, reflecting the more widespread use of longitudinal barrier systems on divided highways. Four-lane twin structures have the lowest involvement (8.7%) with roadside objects other than barriers, indicating the presence of roadsides relatively clear of obstacles in the approach areas to the bridges.

Table 9 shows the distribution of multi-vehicle accidents by manner of collision for the various lane strata. As expected, head-on and sideswipe-

TABLE 8

DISTRIBUTION OF SINGLE VEHICLE ACCIDENTS BY OBJECT STRUCK AND LANE STRATIFICATION

	Object Struck - First Impact														
	Bridge Rail		Bridge End/Pier		Guardrail/ Median Barrier		Other Roadside Object		Ditch/ Embankment		Other/ Unknown Object		No Object Struck		
Lane Stratification	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	Total
One-Lane	4	16.0	1	4.0	2	8.0	6	24.0	3	12.0	3	12.0	6	24.0	25
Undivided Single Structure															
Two-Lane	1312	24.4	466	8.7	767	14.3	836	15.6	485	9.0	454	8.5	1050	19.6	5370
Four-Lane	43	13.0	20	6.0	51	15.4	124	37.3	22	6.6	41	12.3	31	9.3	332
Divided Single Structure															
Four-Lane	83	18.0	16	3.5	157	34.1	88	19.1	22	4.8	44	9.5	51	11.1	461
Other	37	8.3	11	2.5	205	46.2	81	18.2	14	3.2	54	12.2	42	9.5	444
Twin Structures															
Four-Lane	711	20.1	178	5.0	1249	35.3	308	8.7	182	5.1	260	7.3	654	18.5	3542
Other	104	16.2	16	2.5	226	35.3	92	14.4	42	6.6	50	7.8	111	17.3	641
TOTAL	2294	21.2	708	6.6	2657	24.5	1535	14.2	770	7.1	906	8.4	1945	18.0	10815

TABLE 9

DISTRIBUTION OF MULTI-VEHICLE ACCIDENTS BY MANNER OF COLLISION AND LANE STRATIFICATION

	Manner of Collision												
	Head-on		Sideswipe Opposite Direction		Sideswipe Same Direction		Angle		Rear-End		Other		
Lane Stratification	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	Total
One-Lane	1	16.7	1	16.7	1	16.7	0	0.0	1	16.7	2	33.3	6
Undivided Single Structure													
Two-Lane	664	14.5	244	5.3	304	6.6	676	14.8	1170	25.6	1515	33.1	4573
Four-Lane	81	6.5	9	0.7	92	7.4	217	17.5	350	28.2	493	39.7	1242
Divided Single Structure													
Four-Lane	21	2.6	9	1.1	116	14.5	130	16.3	279	35.0	243	30.5	798
Other	15	1.1	1	0.1	284	20.5	109	7.9	576	41.5	403	29.0	1388
Twin Structures													
Four-Lane	74	3.0	14	0.6	468	19.0	390	15.8	1088	44.1	434	17.6	2468
Other	14	1.5	1	0.1	181	19.0	98	10.3	535	56.1	124	13.0	953
TOTAL	870	7.6	279	2.4	1446	12.7	1620	14.2	3999	35.0	3214	28.1	11428

opposite direction collisions are more frequent on undivided roadways while rear-end and sideswipe-same direction accidents are predominant on divided roadways.

The distributions of accident types, object struck for single vehicle accidents, and manner of collision for multi-vehicle accidents by bridge narrowness strata are shown in Tables A.28 to A.30. It is interesting to note that bridge narrowness, defined in terms of percent shoulder reduction, does not appear to have any significant effect on the distribution of accidents. On the other hand, the bridge curb-to-curb width does seem to affect the distribution of accidents. For two-lane undivided single structures, the percentage of single vehicle accidents decreases with increasing bridge curb-to-curb width, from 58 percent for bridges with widths of 18 feet or less to 44.8 percent for those with widths greater than 24 feet. Also, bridges with narrower widths are associated with a greater percentage of single vehicle accidents involving bridge rails and bridge ends as well as higher incidence of head-on and sideswipe-opposite direction collisions for multi-vehicle accidents. This suggests that for bridges with curb-to-curb widths of 24 feet or less, bridge width is a major factor affecting accident occurrence. For bridges with widths greater than 24 feet, bridge width still appears to exert some influence, especially on those with greater than 50 percent shoulder reduction.

2.6.2 Accident Severity

The measure of accident severity used in the study was the highest occupant injury as classified according to the Police Injury Code (PIC) of K = fatal; A = incapacitating injury; B = non-incapacitating injury; C = possible injury, and 0 = no injury or property damage only. Percent of fatal or incapacitating injury (% K + A) accidents is used as a composite measure of accident severity in the remainder of this section.

Table A.31 shows the accident severity by functional classification. Of the 24,809 accidents, 16,481 (66.4%) resulted in no injuries or property damage only; 7,839 (31.6%) resulted in injuries; and 454 (1.8%) resulted in fatalities. Rural bridge accidents have significantly higher severity (% K + A injuries) than urban bridge accidents (11.4% versus 5.8%). For urban highways, the difference in accident severity is not statistically significant between the four functional classes using a chi-square test (see Appendix E for a brief description of the chi-square test). As for rural highways, minor arterials exhibit lower severities and collectors have higher severities, and the differences are statistically significant. These differences in accident severity reflect, to a large extent, the mix of single vehicle versus multi-vehicle accidents on the various highway types. For example, rural highways have a higher percentage of single vehicle accidents than urban highways and thus higher accident severity. Other factors also contribute to the difference in severity, such as higher speeds on rural highways and differences in the mix of object struck and manner of collision for the accidents.

Table 10 shows the distribution of accident severity for the various objects struck in single vehicle accidents. Bridge end/pier accidents are the most severe with 29.8 percent resulting in fatal or incapacitating injuries. While bridge end/pier is involved in only 6.6 percent of single vehicle accidents, it accounts for 31.5 percent (81 out of 257 accidents) of the fatalities and 11.9 percent (130 out of 1,096 accidents) of the incapacitating injuries. Guardrail accidents, on the other hand, have the lowest severity with only 9.5 percent resulting in fatal or incapacitating injuries. This clearly indicates the effectiveness of proper approach guardrail and transition treatments by reducing the severity of bridge end accidents to that of guardrail impacts (i.e., from 29.8% to 9.5% K + A injuries for a potential severity reduction of 68.1%). Non-collision single vehicle accidents, such as rollovers, have the next highest severity (13.9% K + A injuries). Accidents involving bridge rails are more severe than those with guardrails (11.7% versus 9.5%), but are still less than the average of 12.5 percent fatal and incapacitating injuries for all single vehicle accidents. Results of the chi-square test confirm these observations and are highly significant.

The distribution of accident severity by manner of collision in multi-vehicle accidents is illustrated in Table 11. Head-on collisions, as expected, have the highest severity (23.6% K + A injuries), followed by sideswipe-opposite direction impacts (12.2% K + A injuries). On the other hand, sideswipe-same direction (3.0% K + A injuries) and rear-end (4.2% K + A injuries) collisions have the lowest severity. Again, results of the chi-square tests are highly significant. On comparing Tables 10 and 11, it is evident that single vehicle accidents are much more severe than multi-vehicle accidents with more than twice the percentage of fatal

TABLE 10

DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY OBJECT STRUCK

Object Struck - First Impact	Highest Occupant Injury: No Injury No.	%	Possible Injury No.	%	Non-Incapacitating Injury No.	%	Incapacitating Injury No.	%	Fatal No.	%	Total	% Fatal or Incapacitating Injury
Bridge Rail	1361	59.3	193	8.4	472	20.6	238	10.4	30	1.3	2294	11.7
Bridge End/Pier	312	44.1	53	7.5	132	18.6	130	18.4	81	11.4	708	29.8
Guardrail/Median Barrier	1726	65.0	237	8.9	442	16.6	208	7.8	44	1.7	2657	9.5
Other Roadside Object	1001	65.2	136	8.9	244	15.9	126	8.2	26	1.7	1535 (2)	9.9
Ditch/Embankment	437	56.8	89	11.6	154	20.0	82	10.6	8	1.0	770	11.6
Other/Unknown Object	579	63.9	77	8.5	138	15.2	97	10.7	13	1.4	906 (2)	12.1
No Object Struck	995	51.2	255	13.1	424	21.8	215	11.1	55	2.8	1945 (1)	13.9
TOTAL	6411	59.3	1040	9.6	2006	18.5	1096	10.1	257	2.4	10815 (5)	12.5

Note: Number in parenthesis refers to number of accidents with unknown injury severity

TABLE 11

DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY MANNER OF COLLISION

Manner of Collision	Highest Occupant Injury: No Injury No.	No Injury %	Possible Injury No.	Possible Injury %	Non-Incapacitating Injury No.	Non-Incapacitating Injury %	Incapacitating Injury No.	Incapacitating Injury %	Fatal No.	Fatal %	Total	% Fatal or Incapacitating Injury
Head-On	456	52.4	70	8.0	139	16.0	118	13.6	87	10.0	870	23.6
Sideswipe - Opposite Direction	181	64.9	29	10.4	34	12.2	31	11.1	3	1.1	279(1)	12.2
Sideswipe - Same Direction	1214	84.0	101	7.0	87	6.0	39	2.7	5	0.3	1446	3.0
Angle	1127	69.6	169	10.4	222	13.7	89	5.5	13	0.8	1620	6.3
Rear-End	2728	68.2	700	17.5	403	10.1	151	3.8	15	0.4	3999(2)	4.2
Other	2356	73.3	372	11.6	330	10.3	128	4.0	27	0.8	3214(1)	4.8
TOTAL	8062	70.5	1441	12.6	1215	10.6	556	4.9	150	1.3	11428(4)	6.2

Note: Number in parenthesis refers to the number of accidents with unknown injury severity.

and incapacitating injuries (12.5% vs. 6.2%).

Table 12 shows the distribution of accident severity for total accidents by the various lane strata. It is evident that two-lane undivided single structures have significantly higher accident severity (11.4% K + A injuries) than the other structure types. Actually, all other structure types have severity lower than the average, with four-lane twin structures having the next highest severity (8.7% K + A injuries) but still below the average of 8.9 percent. The reasons for such high severity on two-lane undivided single structures can be mostly attributed to the distributions of object struck and manner of collision. However, there may be other underlying factors contributing to the high severity of accidents on two-lane undivided single structures that require further investigation. Similar trends are observed on the distributions of accident severity for single and multi-vehicle accidents, as shown in Tables A.32 and A.33. Results of the chi-square test are highly significant, indicating difference in distribution of accident severity for the various lane strata.

Tables A.34 through A.36 illustrate the distribution of accident severity for total, single vehicle, and multi-vehicle accidents by the various bridge narrowness strata. Bridge narrowness, as defined by percent shoulder reduction, does not appear to have any significant effect on accident severity of single structures. Even for two-lane undivided single structures where accident distribution is affected by the bridge curb-to-curb width, there is no discernible trend that the accident severity is influenced by the bridge width. A possible explanation is that the speeds on narrower bridges are lower and thus result in accidents with lower severity. For twin structures, bridges with greater than 50 percent shoulder reduction show a higher accident severity than bridges with no or 1-50 percent shoulder reduction. More detailed discussions on the effects of bridge narowness on accident severity will be presented in Chapter III.

2.7 Summary

The development of the POPULATION file and descriptive statistics concerning the file have been discussed in this chapter. The POPULATION file contains 11,880 bridges with 24,809 associated accidents that occurred on the bridges or within their approach areas.

The POPULATION file was created using computerized data from five States: Arizona, Michigan, Montana, Texas, and Washington, Numerous

TABLE 12

DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY LANE STRATIFICATION - TOTAL ACCIDENTS

Lane Stratification	Highest Occupant Injury: No Injury No.	%	Possible Injury No.	%	Non-Incapacitating Injury No.	%	Incapacitating Injury No.	%	Fatal No.	%	Total	% Fatal or Incapacitating Injury
One-Lane	18	52.9	4	11.8	9	26.5	2	5.9	0	0.0	34 (1)	5.9
Undivided Single Structure												
Two-Lane	7279	63.5	1091	9.5	1765	15.4	1030	9.0	277	2.4	11468 (26)	11.4
Four-Lane	1277	73.3	190	10.9	176	10.1	74	4.2	25	1.4	1743 (1)	5.6
Divided Single Structure												
Four-Lane	974	72.4	145	10.8	142	10.6	62	4.6	20	1.5	1345 (2)	6.1
Other	1439	74.3	230	11.9	200	10.3	60	3.1	8	0.4	1937	3.5
Twin Structures												
Four-Lane	4401	66.9	704	10.7	904	13.7	455	6.9	116	1.8	6583 (3)	8.7
Other	1093	64.3	272	16.0	235	13.8	89	5.2	8	0.5	1699 (2)	5.7
TOTAL	16481	66.4	2636	10.6	3431	13.8	1772	7.1	454	1.8	24809 (35)	8.9

Note: Number in parenthesis refers to number of accidents with unknown injury severity problems were encountered in the process stemming from data inconsistencies and variations inherent in the State files. Accidents were matched to the bridges using a milepoint matching process. Due to inaccuracies with accident locations, it is not possible to pinpoint the exact location of an accident in relation to the bridge itself. However, it can be identified as occurring with the immediate vicinity of the bridge and its approach with reasonable confidence.

Due to a lack of information on the presence/absence of shoulders and their widths in the POPULATION file, various assumptions based on current design standards were made in determining the narrowness categories of the bridges.

Highlights of the descriptive statistics on the POPULATION file are as follows.

- Since only bridges on State highway systems are included in the study, over 90 percent of the bridges are in rural areas and 81.7 percent of the bridges are two-lane undivided single structures. Two-lane twin strucures account for another 12.1 percent of the bridges. An average bridge has a length of 176 feet and a curb-to-curb width of 31 feet and an approach roadway width of 35.3 feet for a 51.3 percent shoulder reduction. The average bridge was built in 1954 with a remaining life of 25 years. It carries an ADT of 3,703 vehicles with a traffic mix of 11.2 percent trucks.

- Overall, 71.9 percent of single structures are narrow while that for twin structures is only 39 percent based on the narrowness definitions used for the study. Narrow bridges are more prevalent in rural than in urban areas and the percentage of narrow bridges decreases with higher functional class. Also, the presence/absence of shoulders on the approach roadway plays a major role in whether a bridge is categorized as narrow or non-narrow.

- Single vehicle accidents are more frequent (51.9%) on rural bridges while multi-vehicle accidents are predominant (60.5%) on urban bridges. This may partially account for the significantly higher severity of accidents on rural bridges as compared to urban bridges (11.4% versus 5.8% K + A injuries). Other factors may also contribute to this difference in severity, such as higher speeds on rural highways.

- Guardrail/median barrier (24.5%) and bridge rail (21.2%) are the most frequently struck objects in single vehicle accidents. Rear-end collisions are the most frequent (35.0%) for multi-vehicle accidents, followed by angle collisions (14.2%) and sideswipes in the same direction (12.7%).

- Single vehicle accidents are much more severe than multi-vehicle accidents with more than twice the percentage of fatal and incapacitating injuries (12.5% vs. 6.2%).

- Impacts involving bridge ends are by far the most severe (29.8% K + A injuries) while guardrail/median barrier collisions are the least severe (9.5% K + A injuries). By using proper approach guardrails and transition treatments, the severity of bridge end accidents may be reduced by 68.1 percent to that of guardrail impacts.

- For multi-vehicle accidents, head-on and sideswipe-opposite direction collisions are the most severe (23.6% and 12.2% K + A injuries, respectively) while sideswipe-same direction and rear-end collisions are the least severe (3.0% and 4.2% K + A injuries, respectively).

- Single vehicle accidents are the predominant accident type for one-lane (73.5%) and two-lane (46.8%) single structures and for four-lane twin structures (53.8%) while multi-vehicle accidents are the overwhelming majority on the other types of structures.

- Two-lane undivided single structures have significantly higher accident severity (11.4% K + A injuries) than the other structure types.

- The distribution of accidents is affected by bridge curb-to-curb width, but not by bridge narrowness. The percentage of single vehicle accidents increases with decreasing bridge curb-to-curb width. This increase prevails also for the percentage of single vehicle accidents involving bridge rails and bridge ends and for head-on and sideswipe-opposite direction collisions for multi-vehicle accidents.

CHAPTER III. EXTENT OF NARROW BRIDGE ACCIDENT PROBLEM

3.1 Introduction

A primary purpose of the POPULATION file was to determine the extent of the narrow bridge accident problem. This chapter discusses the findings resulting from analyses of data in this file. Included are indications of the total bridge problem, the narrow bridge problem as related to accident rates, and the narrow bridge problem as related to accident severity.

3.1.1 Accident Frequency

Two measures of accident frequencies were used in the analyses as appropriate. These were:

(1) Number of accidents per year per bridge - This is the basic accident frequency count, averaged over the study period of 1975-1977.

$$\text{Accidents/Year/Bridge} = \frac{\text{Number of Accidents/Bridge, 1975-1977}}{3}$$

(2) Number of accidents per year per mile of bridge and approach - This measure takes into account the length of the bridge and the two 500-feet approach areas by converting the accident frequency to a per-mile basis.

$$\text{Accidents/Year/Mile} = \text{Accidents/Year/Bridge} \times \frac{5280}{(\text{Bridge Length} + 1{,}000)}$$

3.1.2 Accident Rate

To convert accident frequency into accident rate, exposure must be taken into consideration. The two most common exposure measures are average daily traffic and vehicle miles of travel, depending on whether a bridge is considered as a spot or a roadway section, respectively. The two measures of accident rate used in the analyses were:

(1) Number of accidents per million (10^6) vehicles - This accident rate measure considers a bridge as a spot or a point and the number of vehicles crossing that point is used as the exposure measure.

$$\text{Accidents}/10^6 \text{ Vehicles} = \text{Accidents/Year/Bridge} \times \frac{1}{365 \times \text{ADT}} \times 10^6$$

(2) Number of accidents per 100 million vehicle miles of travel on bridge and approach - Vehicle miles of travel is used as the exposure

measure with the bridge and its two 500 ft. approaches considered as a roadway section of length equal to the bridge length plus 1,000 feet.

Accidents/100 million (10^8) vehicle miles - bridge and approach

$$= \text{Accidents/Year/Bridge} \times \frac{1}{365 \times \text{ADT}} \times \frac{1}{(\text{Bridge Length} + 1{,}000)} \times 10^8$$

3.1.3 Accident Severity

As previously indicated in Section 2.6.2, the measure of accident severity used in the analyses was the highest occupant injury sustained in the accident as classified according to the Police Injury Code (PIC). These classifications are K = fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury or property damage only. For the purpose of statistical significance testing, the fatal and incapacitating injuries (K and A) are combined as one category and the others (B, C and O) as another category.

3.2 Evaluation of the Total Bridge Problem

As a first step in determining the extent of the bridge accident problem, it is desirable to compare average accident rates on a roadway with the rates of the bridge-related accidents. Obviously, the best measure would be total accidents. However, such information is difficult to obtain. Fatal and injury accidents are reported annually by the States on the required FHWA TA-1 forms. A sample of 13 States which report total accidents and accident rates was used in Reference 19 in an attempt to extrapolate these fatal/injury accidents to total accidents. However, the analysis and estimate of total accidents were admittedly gross. In Réference 20, more than 24,000 bridge accidents in Alabama between 1972 and 1979 were analyzed. The results show a definite transition from the roadway accident rate to the bridge accident rate, with a maximum rate at the bridge abutment of more than twice the roadway rate. However, the approach accident increase could not be identified as any standard statistical distribution, primarily because of the tenth milepoint preference of investigating officers.

It was decided to use the fatal and injury accident rates derived from the TA-1 forms as the most reliable basis of comparison. Table 13 shows these average accident rates by highway system and the corresponding bridge-related rates as determined from the analysis of the POPULATION

TABLE 13

COMPARISON OF AVERAGE AND BRIDGE-RELATED ACCIDENT RATES

Highway System	Fatal Accident Rate ($Acc/10^8$ Vehicle-Miles)			Non-Fatal Injury Accident Rate ($Acc/10^8$ Vehicle-Miles)		
	Average*	Bridge-Related	%**	Average*	Bridge-Related	%**
Interstate, Rural Arterial	1.59	3.53	222.0	27.43	61.82	225.4
Interstate, Urban Arterial	1.18	2.87	243.2	55.11	63.92	116.0
Federal-Aid Primary, Rural Arterial	3.96	7.73	195.2	74.54	108.03	144.9
Federal-Aid Primary, Urban Arterial	2.31	2.14	92.6	149.58	79.57	53.2
Federal-Aid Urban, Arterial	2.53	2.75	108.7	208.97	101.60	48.6
Federal-Aid Urban, Collector	2.31	9.16	396.5	232.20	87.97	37.9
Federal-Aid Secondary, Rural Collector	5.06	11.98	236.8	123.40	139.70	113.2
Non-Federal-Aid, Rural***	4.53	8.29	183.0	145.65	130.33	89.5
Non-Federal-Aid, Urban Arterial	1.97	--	--	184.76	--	--
Non-Federal-Aid, Urban Collector	2.95	--	--	276.52	--	--
Non-Federal-Aid, Rural Local	4.88	--	--	172.07	--	--
Non-Federal-Aid, Urban Local	1.99	--	--	198.44	--	--

* Source: Reference 21

$$** \% = \frac{\text{Bridge-Related Accident Rate}}{\text{Average Accident Rate}} \times 100\%$$

*** Average of Non-Federal-Aid Rural Arterials and Collectors file. It can be seen from the table that, except for federal-aid urban arterials, bridge-related fatal accident rates are significantly higher than the average in all categories. Bridge-related non-fatal injury accident rates are also higher than the average for interstates and rural arterials and collectors, but lower for urban arterials and collectors. It can be concluded that a safety problem does exist with bridges in general, particularly with interstate and rural highways. In the following sections, the problem is further evaluated with respect to bridge narrowness.

Table 14 summarizes the POPULATION file for the total and single vehicle accident frequencies and rates for the various functional classes. Accident frequencies are much higher on urban bridges than on rural bridges on both total and single vehicle accidents. The obvious reason is the higher traffic volume in urban areas. Once the traffic exposures are taken into account, the accident rates are higher on rural bridges than on urban bridges. Another important observation is the predominance of multi-vehicle accidents in urban areas (64%) and single vehicle accidents in rural areas (61%). In terms of highway types, interstate bridges have the highest accident frequencies but the lowest accident rates, again reflecting the effect of traffic volumes. The accident frequencies decline with lower highway types while the accident rates increase so that bridges on collectors have the lowest accident frequencies but the highest accident rates.

3.3 Evaluation of Bridge Narrowness as Related to Accident Rates

Tables 15 and 16 summarize the total and single vehicle accident frequencies and rates for the various bridge narrowness strata, respectively. With the large number of bridge narrowness strata, the trends are not as evident as in Table 14, but are nonetheless present. The inherent differences between urban and rural bridges and the effect of traffic volume are indirectly reflected in the accident frequencies and rates.

Accident frequencies are highest on multi-lane (more than 4) facilities, followed by four-lane divided and undivided single structures, four-lane twin structures, two-lane undivided single structures, and finally one-lane bridges. The reverse order is true for accident rates in general. Also, the predominances of multi-vehicle accidents on urban bridges and single-vehicle accidents on rural bridges have some effect on the variations in ordering between total and single vehicle accident frequencies and rates.

The key question addressed in the POPULATION file was whether there are statistically significant differences in these accident rates

TABLE 14

TOTAL AND SINGLE VEHICLE ACCIDENT FREQUENCIES AND RATES BY FUNCTIONAL CLASSIFICATION

Functional Classification	N Bridges (p24)	Total Accidents: Accident Frequency Acc/Yr	Total Accidents: Accident Frequency Acc/Yr/Mi	Total Accidents: Accident Rate Acc/10^6 Vehicles	Total Accidents: Accident Rate Acc/10^8 Vehicle-Miles
Urban Interstate	323	5.04	20.65	0.517	219.6
Urban Major Arterial	622	2.66	11.41	0.656	286.2
Urban Minor Arterial	206	1.58	7.16	0.852	386.0
Urban Collector	26	0.78	3.52	0.479	218.8
URBAN TOTAL	1177	3.08	13.02	0.649	284.0
Rural Interstate	839	1.09	4.67	0.456	195.1
Rural Major Arterial	2109	0.71	3.10	0.634	279.7
Rural Minor Arterial	2246	0.51	2.31	0.762	343.5
Rural Collector	5509	0.20	0.94	0.812	370.4
RURAL TOTAL		0.44	1.94	0.738	333.2
GRAND TOTAL		0.70	3.04	0.729	328.3

Functional Classification	Single Vehicle Accidents: Acc/Yr	Single Vehicle Accidents: Acc/Yr/Mi	Single Vehicle Accidents: Acc/10^6 Vehicles	Single Vehicle Accidents: Acc/10^8 Vehicle-Miles
Urban Interstate	1.93	8.16	0.253	108.9
Urban Major Arterial	0.91	3.87	0.244	105.8
Urban Minor Arterial	0.50	2.25	0.330	150.0
Urban Collector	0.26	1.19	0.200	91.2
URBAN TOTAL	1.10	4.70	0.261	114.1
Rural Interstate	0.74	3.15	0.346	148.2
Rural Major Arterial	0.43	1.89	0.414	184.2
Rural Minor Arterial	0.30	1.33	0.516	233.8
Rural Collector	0.13	0.62	0.618	282.0
RURAL TOTAL	0.27	1.22	0.535	242.2
GRAND TOTAL	0.36	1.56	0.508	229.6

TABLE 15

TOTAL ACCIDENT FREQUENCIES AND RATES BY BRIDGE NARROWNESS STRATA

Bridge Narrowness Strata					Total Accidents			
					Accident Frequency		Accident Rate	
		No. Lanes	Bridge Width	Shoulder Reduction	Acc/Yr/Br	Acc/Yr/Mi	Acc/10^6 Vehicles	Acc/10^8 Vehicle-Miles
Single Structures	Undivided	1	≤18'	-	0.12	0.60	1.177	557.9
			>18'	-	0.15	0.76	2.025	938.6
		2	≤18', <Approach	-	0.38	1.69	1.884	813.5
			≤18', >Approach	-	0.09	0.44	0.751	342.5
			18'-20', <Approach	-	0.25	1.09	1.036	474.0
			18'-20', ≥Approach	-	0.11	0.49	0.765	366.8
			20'-22', <Approach	-	0.48	2.01	1.194	538.4
			20'-22', ≥Approach	-	0.28	1.24	1.213	560.3
			22'-24', <Approach	-	0.35	1.56	0.816	369.0
			22'-24', ≥Approach	-	0.21	0.97	0.874	397.9
			>24'	>50%	0.70	2.92	0.746	315.9
			>24'	1-50%	0.45	2.10	0.661	304.8
			>24'	None	0.37	1.71	0.586	268.3
		4	N/A	>50%	2.95	12.92	0.876	391.4
				1-50%	1.47	6.45	0.597	264.1
				None	2.11	9.81	0.791	362.8
	Divided	4	N/A	>50%	2.99	11.48	0.681	260.7
				1-50%	2.15	9.41	0.565	233.9
				None	2.57	10.08	0.498	196.3
		Other	N/A	>50%	14.24	47.68	0.790	289.7
				1-50%	3.48	15.55	0.407	181.4
				None	4.28	19.17	0.398	174.3
Twin Structures	Divided	2	≤24'	-	1.66	6.35	0.577	223.8
			>24'	>50%	2.35	9.53	0.562	224.7
			>24'	1-50%	1.72	7.37	0.452	195.0
			>24'	None	1.16	5.28	0.437	198.5
		Other	N/A	>50%	6.17	27.04	0.753	314.2
				1-50%	8.35	32.39	0.834	339.1
				None	4.75	20.99	0.562	250.0
TOTAL					0.70	3.04	0.729	328.3

TABLE 16

SINGLE VEHICLE ACCIDENT FREQUENCIES AND RATES BY BRIDGE NARROWNESS STRATA

Bridge Narrowness Strata					Single Vehicle Accidents			
					Accident Frequency		Accident Rate	
		No. Lanes	Bridge Width	Shoulder Reduction	Acc/Yr/Br	Acc/Yr/Mi	Acc/10^6 Vehicles	Acc/10^8 Vehicle-Miles
Single Structures	Undivided	1	≤18'	-	0.09	0.43	0.882	417.0
			>18'	-	0.15	0.76	2.025	938.6
		2	≤18', <Approach	-	0.25	1.12	0.927	406.8
			≤18', ≥Approach	-	0.06	0.27	0.501	225.7
			18'-20', <Approach	-	0.16	0.71	0.812	375.0
			18'-20', ≥Approach	-	0.07	0.32	0.564	268.2
			20'-22', <Approach	-	0.26	1.12	0.905	414.1
			20'-22', ≥Approach	-	0.21	0.93	0.875	403.3
			22'-24', <Approach	-	0.21	0.94	0.614	279.1
			22'-24', ≥Approach	-	0.13	0.59	0.673	305.5
			>24'	>50%	0.37	1.55	0.452	191.6
			>24'	1-50%	0.27	1.26	0.457	210.1
			>24'	None	0.21	0.97	0.408	186.9
		4	N/A	>50%	0.91	4.04	0.342	153.3
				1-50%	0.31	1.39	0.167	75.2
				None	0.52	2.42	0.254	116.2
	Divided	4	N/A	>50%	0.98	3.79	0.277	105.9
				1-50%	0.90	3.89	0.303	119.3
				None	1.13	4.48	0.260	105.5
		Other	N/A	>50%	2.43	8.43	0.176	66.2
				1-50%	1.65	7.40	0.185	82.1
				None	1.41	6.21	0.166	71.1
Twin Structures	Divided	2	≤24'	-	1.03	3.77	0.371	138.0
			>24'	>50%	1.40	5.65	0.391	155.6
			>24'	1-50%	0.93	3.94	0.308	133.0
			>24'	None	0.71	3.22	0.307	139.9
		Other	N/A	>50%	3.93	17.27	0.616	254.1
				1-50%	3.41	12.98	0.383	152.5
				None	1.64	7.29	0.312	94.9
TOTAL					0.36	1.56	0.508	229.6

between the various bridge narrowness strata. The following three separate sets of statistical analyses were used in the analyses:

(1) Pairwise comparison of mean accident rates

(2) One-way and two-way analysis of variance (ANOVA) with pairwise comparison of mean accident rates (Duncan Multiple Range test)

(3) Non-parametric one-way analysis of variance (NPARIWAY) with pairwise comparison of mean rank scores (multiple comparisons).

Brief discussions of these methods are included in Appendix E and will not be repeated here. All illustrations shown in this chapter are based on mean accident rates for ease of comprehension. Corresponding illustrations based on mean rank scores (NPARIWAY) are shown in Appendix F. However, much of the statistical testings are based on the non-parametric mean rank scores in order to account for the Poisson distribution of accident frequencies and rates on individual bridges and to moderate the effect of large percentage of bridges having zero accident rates while a few bridges have very high accident rates.

These statistical tests were conducted for each of the following bridge types:

(1) One-lane single structures

(2) Two-lane undivided single structures

(3) Four-lane undivided single structures

(4) Four-lane divided single structures

(5) Other divided single structures

(6) Four-lane twin structures

(7) Other twin structures.

These bridge types were analyzed separately because of the inherent differences between them. Discussions of the results for each bridge type follow.

3.3.1 <u>One-Lane Bridges</u>

As illustrated in Figure 2, the mean accident rates, both for total accidents and single vehicle accidents, are higher for one-lane bridges with curb-to-curb width greater than 18 feet than for those with curb-to-curb width equal to or less than 18 feet. The same is true for mean rank scores (Figure A.2 in Appendix F) though the differences are much smaller, indicating the effect of a large proportion of bridges with zero accident rates and a small percentage of bridges with high accident rates. However,

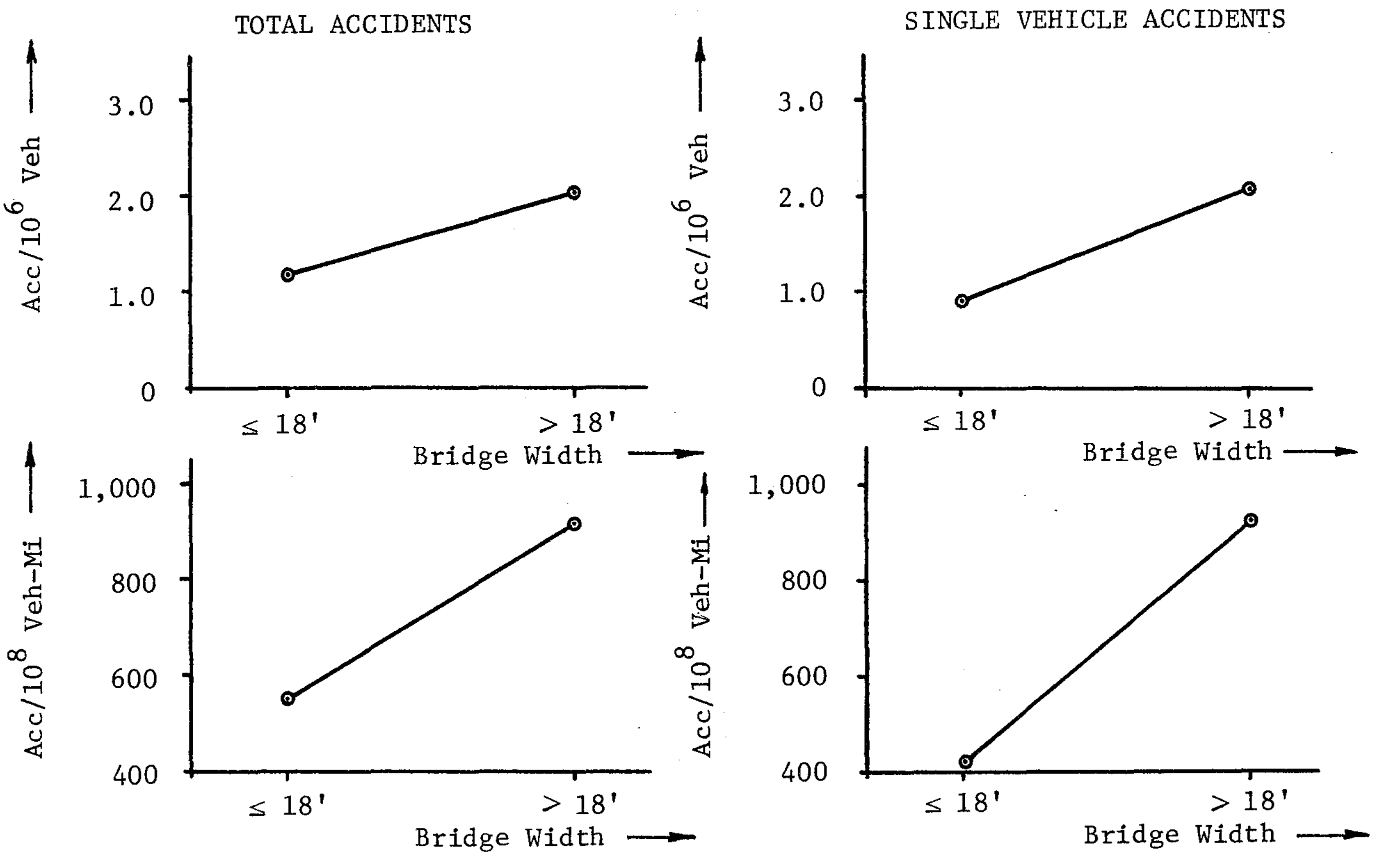


FIGURE 2. MEAN ACCIDENT RATES FOR ONE-LANE SINGLE STRUCTURES

all statistical tests turn out to be insignificant, suggesting that the accident rates are not statistically different between those one-lane bridges with curb-to-curb widths less than or equal to 18 feet and those over 18 feet. It should be cautioned that the sample size for one-lane bridges is rather small to attach much significance to the statistical test results.

3.3.2 Two-Lane Undivided Single Structures

Figure 3 illustrates the mean accident rates for two-lane undivided single structures of various bridge curb-to-curb widths (i.e., $\leq$ 18′, 18.1′-20.0′, 20.1′-22.0′, 22.1′-24.0′ and > 24.0′) and narrowness (i.e., narrow = bridge < approach width vs. non-narrow = bridge $\geq$ approach width). Corresponding illustrations on mean rank scores are shown in Figure A.3. Note that the definition for narrowness has been slightly modified for application to bridges with widths of 24 feet or less.

Results of the NPARIWAY and ANOVA analyses indicate that, overall, both bridge curb-to-curb widths and narrowness have highly significant effects (< 1 percent significance level) on accident rates and rank scores individually but do not interact. In other words, the bridge width has significant effects on accident rates as does bridge narrowness, but combinations of bridge width and narrowness are not significant. However, results of the pairwise comparisons are much harder to interpret, suggesting that there are factors other than bridge width and narrowness affecting the accident rates.

For narrow bridges (i.e., bridge < approach width), the mean accident rates generally decline with increasing bridge width except for a secondary peak for bridges with widths between 20 and 22 feet. However, for non-narrow bridges (i.e., bridge $\geq$ approach width), the highest mean accident rates are at bridge widths between 20 and 22 feet. Also, the mean accident rates for bridges over 20 feet are very close between narrow and non-narrow bridges. As expected, significant differences in mean accident rates between narrow and non-narrow bridges are detected for bridge widths less than 20 feet, but the differences are insignificant for widths greater than 20 feet.

In terms of mean rank scores, the pattern is different from that of mean accident rates. Non-narrow bridges consistently have lower mean rank scores than narrow bridges of the same widths, and the differences are generally significant. However, concerning the effect of bridge widths,

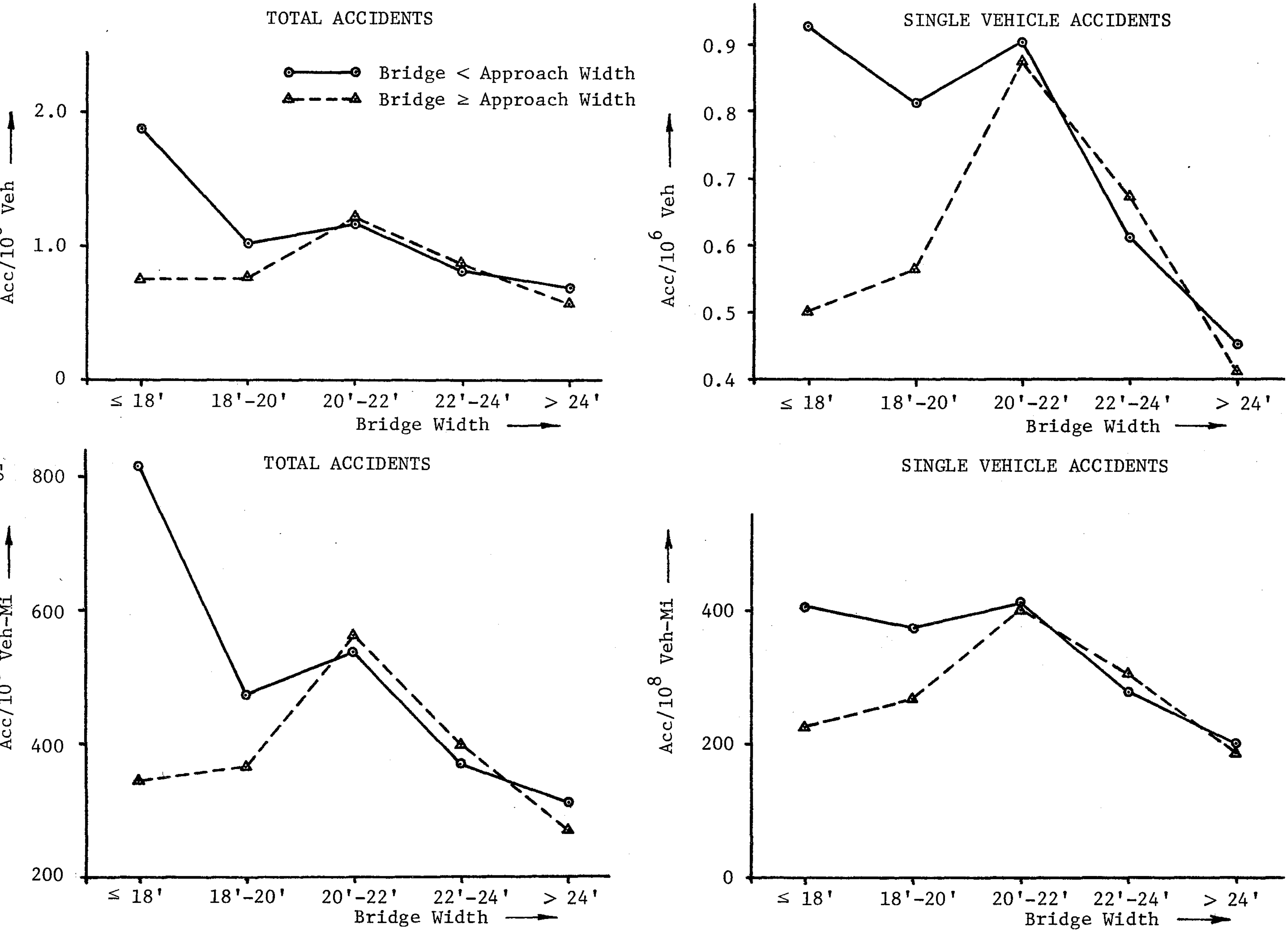


FIGURE 3. MEAN ACCIDENT RATES FOR TWO-LANE UNDIVIDED SINGLE STRUCTURES

a W-pattern is evident with high rank scores for bridges with widths less than 18 feet, between 20 and 22 feet, and greater than 24 feet and low rank scores for bridges with widths between 18 and 20 feet and between 22 and 24 feet. The differences in mean rank scores are significant between the two groups, but not within them. There are no apparent explanations for such results.

3.3.3 Four-Lane Undivided Single Structures

Figure 4 shows the mean accident rates on both total and single vehicle accidents for four-lane undivided single structures. The mean accident rates exhibit a peculiar W-pattern so that bridges with shoulder reduction of 1-50 percent have the lowest mean accident rates. In comparison, the mean rank scores (Figure A.4) indicate that bridges with no and 1-50 percent shoulder reduction have similar scores.

Results of the analysis support the contention that there are insignificant differences in accident rates and rank scores between bridges with no and 1-50 percent shoulder reduction. However, significant differences do exist between bridges with greater than 50 percent shoulder reduction and those with no or 1-50 percent shoulder reduction. The significance is marginal (10 percent significance level) for total accidents and somewhat stronger for single vehicle accidents (5 percent signficance level).

3.3.4 Four-Lane Divided Single Structures

The mean accident rates and mean rank scores on both total and single vehicle accidents for four-lane divided single structures are graphically displayed in Figure 5 and Figure A.5, respectively. Conflicting patterns between mean accident rates and mean rank scores are evident from the graphs with no apparent trend. All statistical tests turn out to be insignificant, leading to the conclusion that shoulder reduction has little or no effect on accidents for four-lane divided single structures.

3.3.5 Other Divided Single Structures

Figure 6 illustrates the mean accident rates and mean rank scores on both total and single vehicle accidents for divided single structures with more than four lanes. Corresponding illustration on mean rank scores is shown in Figure A.6. The data indicates no apparent trends, suggesting that shoulder reduction has little or no effect on accidents. Results of the analysis show no significant differences in all statistical tests on the accident rates and rank scores.

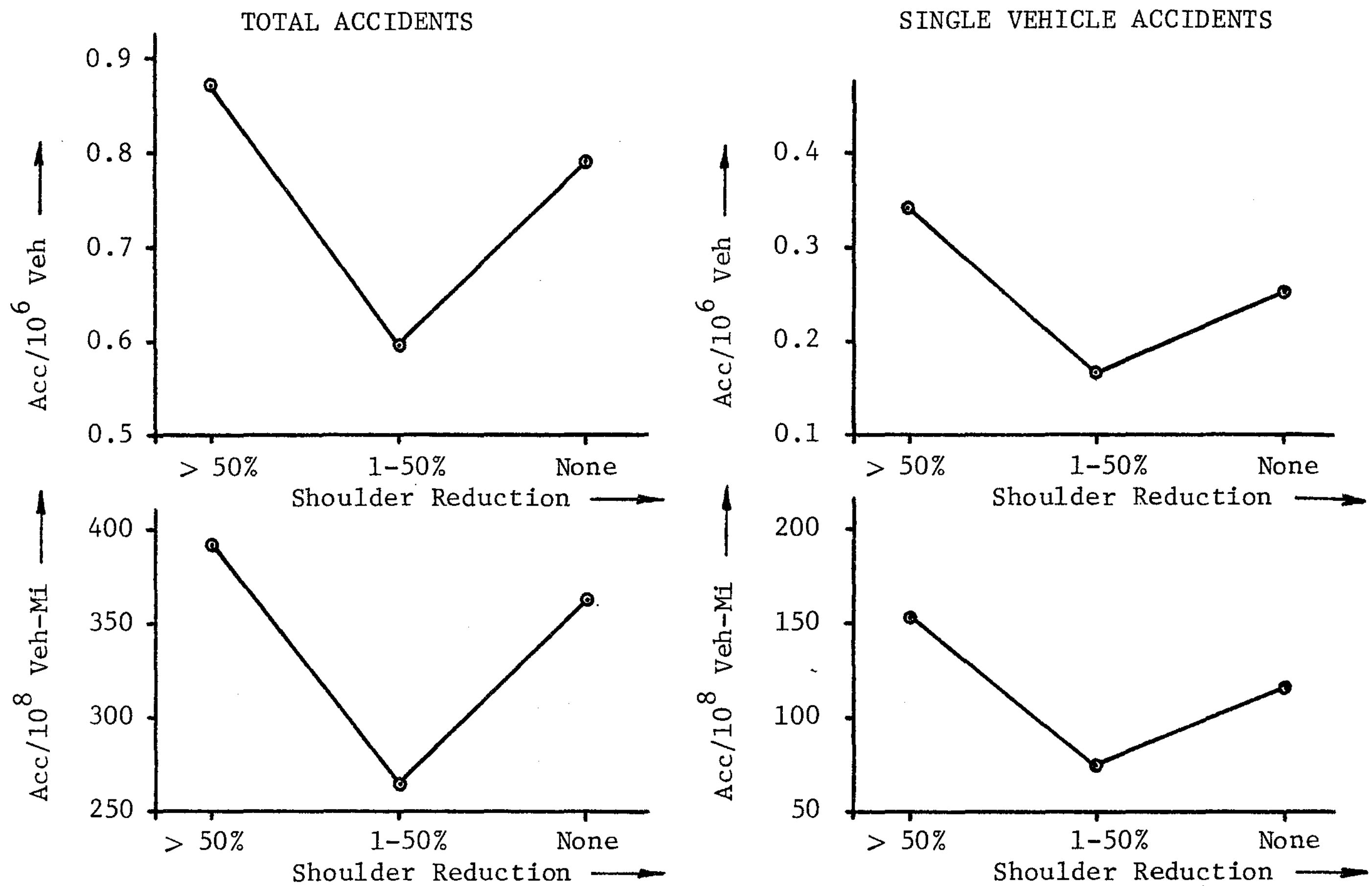


FIGURE 4. MEAN ACCIDENT RATES FOR FOUR-LANE UNDIVIDED SINGLE STRUCTURES

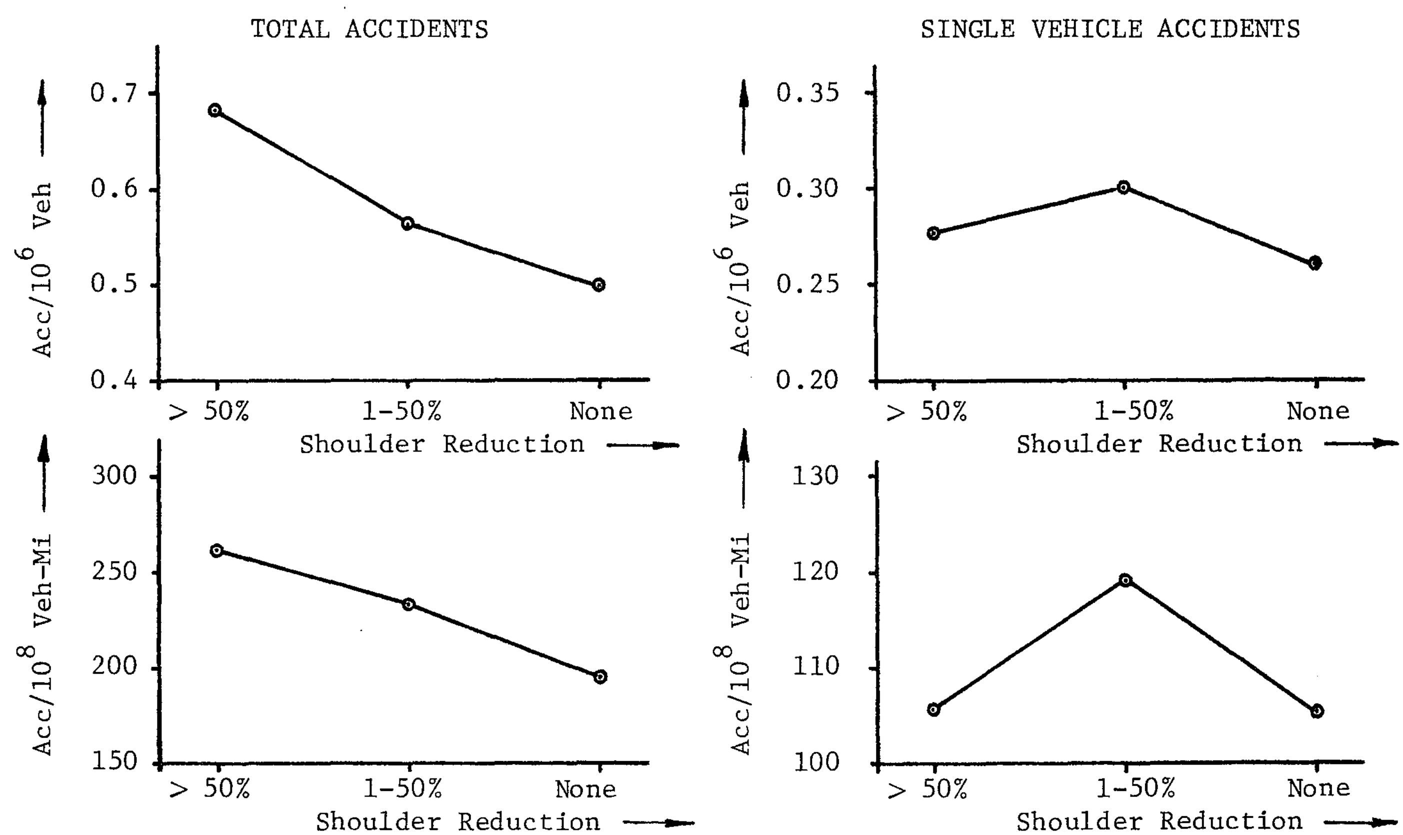


FIGURE 5. MEAN ACCIDENT RATES FOR FOUR-LANE DIVIDED SINGLE STRUCTURES

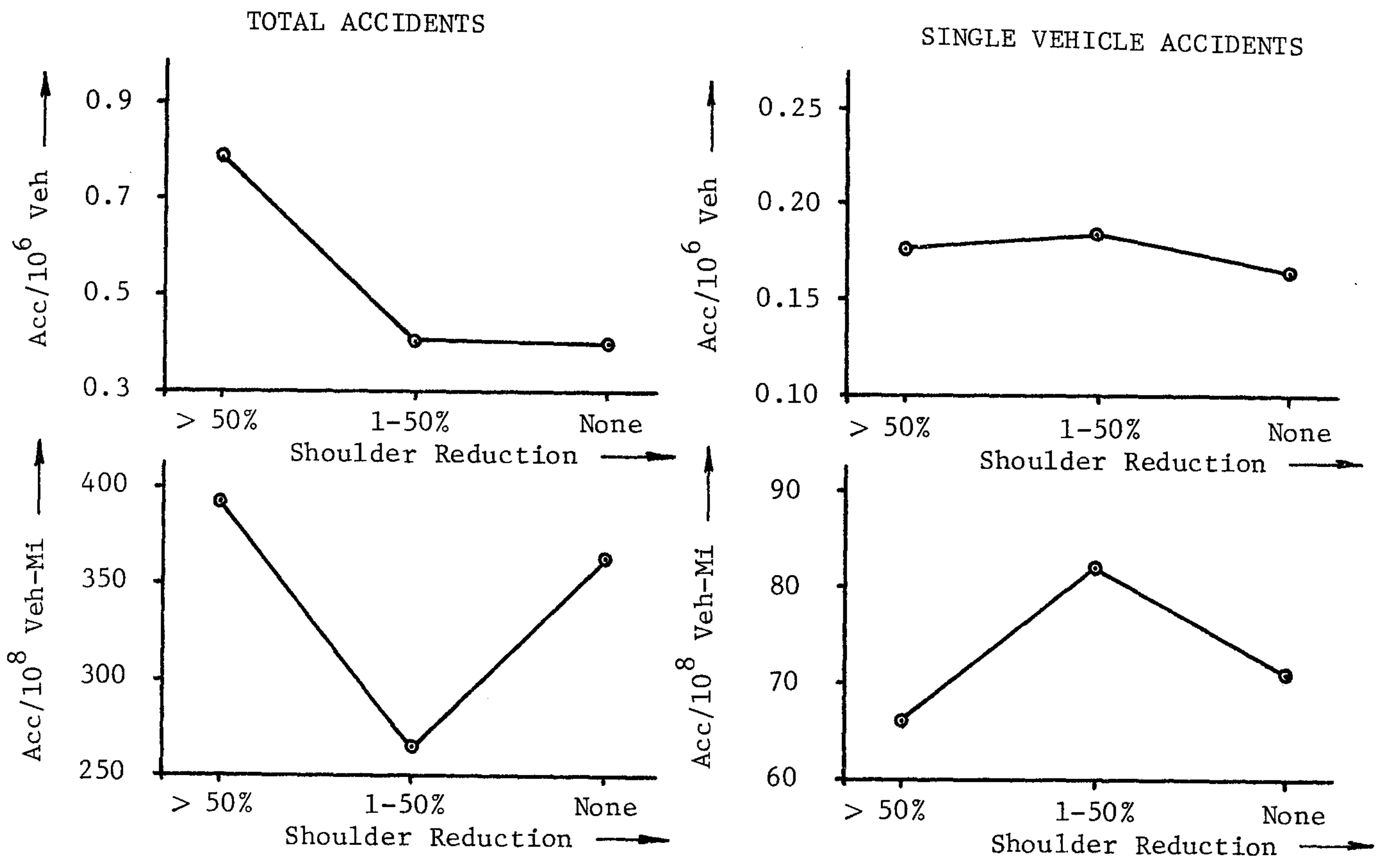


FIGURE 6. MEAN ACCIDENT RATES FOR OTHER (≠ 4-LANE) DIVIDED SINGLE STRUCTURES

3.3.6 Four-Lane Twin Structures

The mean accident rates and mean rank scores on both total and single vehicle accidents for four-lane twin structures are illustrated in Figure 7 and Figure A.7, respectively. A visual examination of the data indicates that the mean accident rates and mean rank scores exhibit similar trends with two distinct groups. Bridges with curb-to-curb widths less than or equal to 24 feet and those with greater than 50 percent shoulder reduction have similar accident rates and rank scores while bridges with no or less than 50 percent shoulder reduction are closely together.

Analysis results validate the visual observations, and the differences in mean accident rates and mean rank scores are highly significant (1 percent significance level) between the two groups, but insignificant within the group. The significance is much stronger for accidents per million vehicles than for accidents per 100 million vehicle-miles, although both measures are significant.

3.3.7 Other Twin Structures

Figure 8 shows the mean accident rates on both total and single vehicle accidents for twin structures with more than four lanes. Corresponding illustration for mean rank scores is shown in Figure A.8. Bridges with no shoulder reduction (non-narrow) consistently have lower mean accident rates and mean rank scores than narrow bridges with some shoulder reduction. The differences are more pronounced for single vehicle accidents than for total accidents.

Results of the analysis confirm the visual observation in that the differences between mean accident rates and mean rank scores are statistically insignificant for total accidents, but marginally significant for single vehicle accidents (NPARIWAY significant at 10 percent significance level; ANOVA at 95 percent level; Z-test insignificant). Multiple comparisons indicate that the significance is attributable to the differences between non-narrow bridges and those with greater than 50 percent shoulder reduction.

3.4 Evaluation of Bridge Narrowness as Related to Accident Severity

The distributions of accident severity for total, single vehicle, and multi-vehicle accidents by bridge narrowness strata are shown in Tables 17 through 19. Statistical significance tests, principally the chi-square test (see Appendix E), were conducted to determine if bridge narrowness

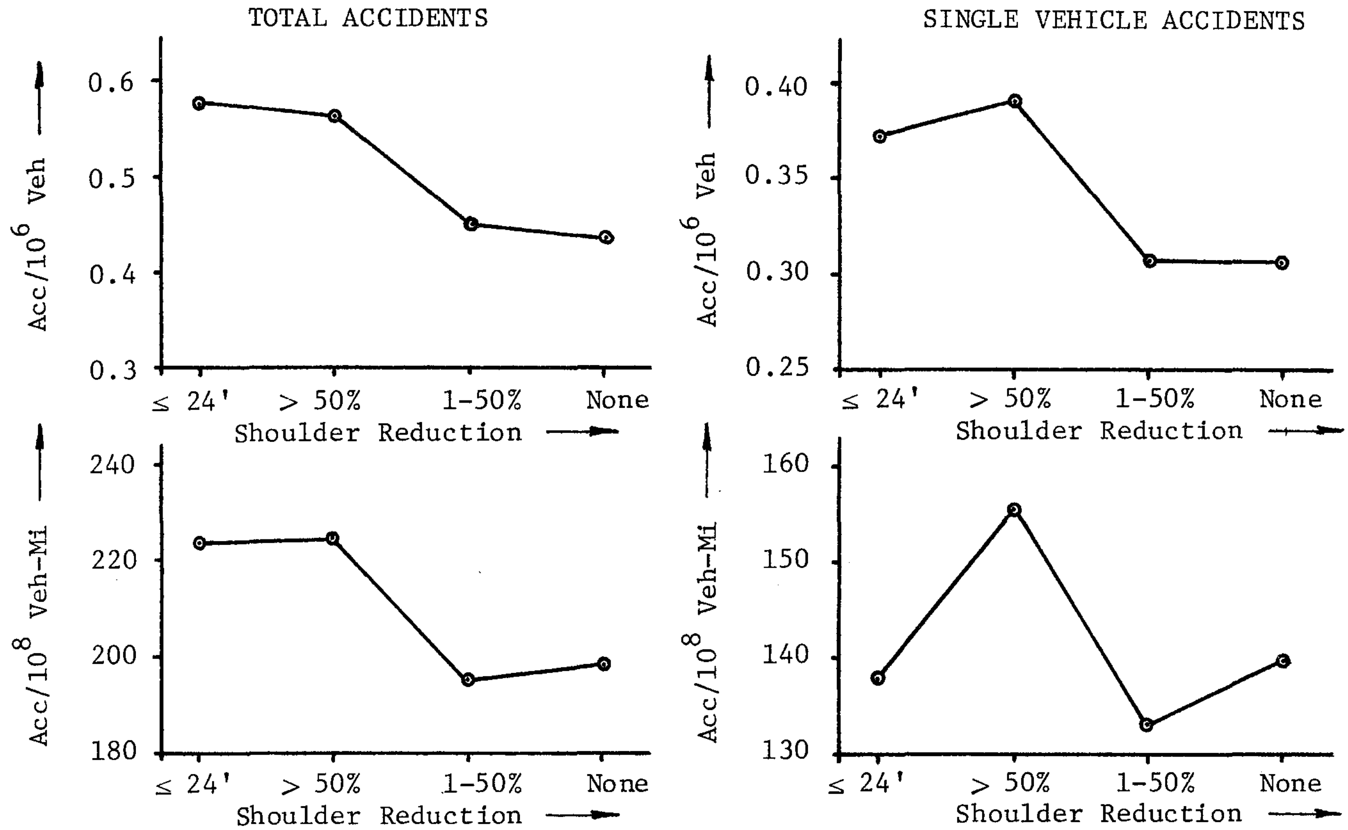


FIGURE 7. MEAN ACCIDENT RATES FOR FOUR-LANE TWIN STRUCTURES

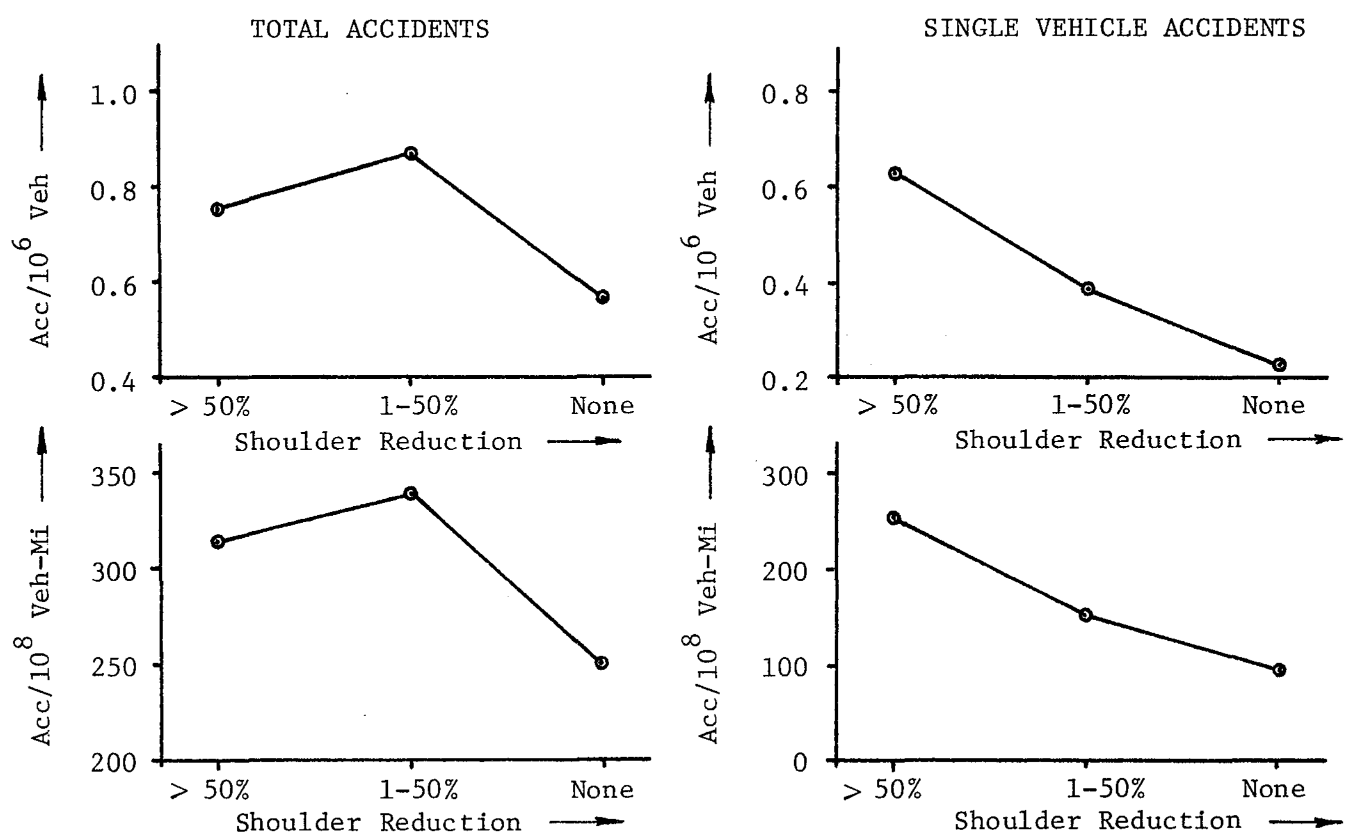


FIGURE 8. MEAN ACCIDENT RATES FOR OTHER (≠ 4-LANE) TWIN STRUCTURES

TABLE 17

DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY BRIDGE NARROWNESS STRATA - TOTAL ACCIDENTS

Bridge Narrowness Strata		No. Lanes	Bridge Width	Shoulder Reduction	No Injury No.	No Injury %	Possible Injury No.	Possible Injury %	Non-Incapacitating Injury No.	Non-Incapacitating Injury %	Incapacitating Injury No.	Incapacitating Injury %	Fatal No.	Fatal %	Total	% Fatal or Incapacitating Injury
Single Structures	Undivided	1	≤18'	-	18	64.3	4	14.3	5	17.9	0	0.0	0	0.0	28	0.0
			>18'	-	0	0.0	0	0.0	4	66.7	2	33.3	0	0.0	6	33.3
		2	<18', <Approach	-	56	63.6	7	8.0	11	12.5	11	12.5	3	3.4	88	15.9
			≤18', ≥Approach	-	2	40.0	0	0.0	2	40.0	1	20.0	0	0.0	5	20.0
			18'-20', <Approach	-	331	62.1	52	9.8	80	15.0	51	9.6	14	2.6	533	12.2
			18'-20', ≥Approach	-	73	77.7	6	6.4	9	9.6	5	5.3	1	1.1	94	6.4
			20'-22', <Approach	-	359	63.7	56	9.9	79	14.0	57	10.1	11	2.0	564	12.1
			20'-22', ≥Approach	-	64	55.2	11	9.5	28	24.1	10	8.6	3	2.6	116	11.2
			22'-24', <Approach	-	1119	61.7	163	9.0	314	17.3	162	8.9	53	2.9	1814	11.8
			22'-24', ≥Approach	-	373	64.0	44	7.5	77	13.2	70	12.0	19	3.3	583	15.3
			>24'	>50%	1725	63.9	276	10.2	420	15.6	214	7.9	58	2.1	2699	10.0
			>24'	1-50%	1221	64.9	176	9.4	278	14.8	156	8.3	47	2.5	1881	10.8
			>24'	None	1956	63.3	300	9.7	467	15.1	293	9.5	68	2.2	3091	11.7
		4	N/A	>50%	335	71.9	45	9.7	55	11.8	23	4.9	8	1.7	466	6.6
				1-50%	77	67.0	19	16.5	14	12.2	3	2.6	1	0.9	115	3.5
				None	865	74.4	126	10.8	107	9.2	48	4.1	16	1.4	1162	5.5
	Divided	4	N/A	>50%	532	74.5	74	10.4	67	9.4	31	4.3	8	1.1	714	5.4
				1-50%	291	70.0	46	11.1	51	12.3	20	4.8	8	1.9	416	6.7
				None	151	70.2	25	11.6	24	11.2	11	5.1	4	1.9	215	7.0
		Other	N/A	>50%	863	75.8	135	11.9	109	9.6	28	2.5	3	0.3	1138	2.8
				1-50%	148	74.0	21	10.5	23	11.5	6	3.0	2	1.0	200	4.0
				None	428	71.5	74	12.4	68	11.4	26	4.3	3	0.5	599	4.8
Twin Structures	Divided	2	≤24'	-	117	71.3	10	6.1	20	12.2	13	7.9	4	2.4	164	10.3
			>24'	>50%	1399	63.6	255	11.6	325	14.8	175	8.0	43	2.0	2199	10.0
			>24'	1-50%	767	66.3	137	11.8	178	15.4	55	4.8	19	1.6	1157	6.4
			>24'	None	2118	69.1	302	9.9	381	12.4	212	6.9	50	1.6	3063	8.5
		Other	N/A	>50%	162	58.5	37	13.4	48	17.3	28	10.1	1	0.4	277	10.5
				1-50%	279	69.6	63	15.7	48	12.0	10	2.5	1	0.2	401	2.7
				None	652	63.9	172	16.8	139	13.6	51	5.0	6	0.6	1021	5.6
TOTAL					16481	66.4	2636	10.6	3431	13.8	1772	7.1	454	1.8	24809	8.9

TABLE 18

DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY BRIDGE NARROWNESS STRATA - SINGLE VEHICLE ACCIDENTS

Bridge Narrowness Strata					Highest Occupant Injury											
		No. Lanes	Bridge Width	Shoulder Reduction	No Injury		Possible Injury		Non-Incapacitating Injury		Incapacitating Injury		Fatal			% Fatal or Incapacitating Injury
					No.	%	No.	%	No.	%	No.	%	No.	%	Total	
Single Structures	Undivided	1	≤18'	-	12	63.2	2	10.5	4	21.1	0	0.0	0	0.0	19	0.0
			>18'	-	0	0.0	0	0.0	4	66.7	2	33.3	0	0.0	6	33.3
		2	≤18', <Approach	-	25	49.0	6	11.8	9	17.6	9	17.6	2	3.9	51	21.5
			≤18', >Approach	-	1	33.3	0	0.0	1	33.0	1	33.0	0	0.0	3	33.0
			18'-20', ≤Approach	-	171	57.0	30	10.0	54	18.0	35	11.7	10	3.3	300	15.0
			18'-20', >Approach	-	33	66.0	5	10.0	7	14.0	5	10.0	0	0.0	50	10.0
			20'-22', ≤Approach	-	151	57.4	22	8.4	49	18.6	38	14.4	3	1.1	263	15.5
			20'-22', >Approach	-	37	50.0	8	10.8	20	27.0	8	10.8	1	1.4	74	12.2
			22'-24', ≤Approach	-	484	53.5	78	8.6	204	22.6	108	11.9	30	3.3	904	15.2
			22'-24', >Approach	-	149	52.3	22	7.7	47	16.5	52	18.2	15	5.3	285	23.5
			≥24'	>50%	695	58.9	102	8.6	235	19.9	114	9.7	34	2.9	1180	12.6
			>24'	1-50%	475	56.2	71	8.4	171	20.2	101	12.0	27	3.2	845	15.2
			>24'	None	751	53.1	149	10.5	308	21.8	176	12.4	28	2.0	1415	14.4
		4	N/A	>50%	73	69.5	9	8.6	18	17.1	3	2.9	2	1.9	105	4.8
				1-50%	15	65.2	3	13.0	4	17.4	0	0.0	1	4.3	23	4.3
				None	131	64.2	26	12.7	34	16.7	8	3.9	5	2.5	204	6.4
	Divided	4	N/A	>50%	146	68.2	19	8.9	29	13.6	17	7.9	3	1.4	214	9.3
				1-50%	100	62.9	16	10.1	27	17.0	11	6.9	5	3.1	159	10.0
				None	62	70.5	9	10.2	6	6.8	9	10.2	2	2.3	88	12.5
		Other	N/A	>50%	115	64.6	20	11.2	34	19.1	9	5.1	0	0.0	178	5.1
				1-50%	57	68.7	8	9.6	15	18.1	3	3.6	0	0.0	83	3.6
				None	126	68.9	17	9.3	28	15.3	12	6.6	0	0.0	183	6.6
Twin Structures	Divided	2	<24'	-	61	64.2	5	5.3	16	16.8	10	10.5	3	3.2	95	13.7
			≥24'	>50%	729	59.2	122	9.9	217	17.6	133	10.8	31	2.5	1232	13.3
			>24'	1-50%	347	60.2	61	10.6	116	20.1	39	6.8	12	2.1	576	8.9
			>24'	None	1073	65.5	155	9.5	231	14.1	141	8.6	39	2.4	1639	11.0
		Other	N/A	>50%	92	55.1	18	10.8	33	19.8	24	14.4	0	0.0	167	14.4
				1-50%	99	66.4	18	12.1	24	16.1	7	4.7	1	0.7	149	5.4
				None	201	61.8	39	12.0	61	18.8	21	6.5	3	0.9	325	7.4
TOTAL					6411	59.3	1040	9.6	2006	18.5	1096	10.1	257	2.4	10815	12.5

TABLE 19

DISTRIBUTION OF HIGHEST OCCUPANT INJURY BY BRIDGE NARROWNESS STRATA - MULTI-VEHICLE ACCIDENTS

Bridge Narrowness Strata					Highest Occupant Injury											
		No. Lanes	Bridge Width	Shoulder Reduction	No Injury No.	No Injury %	Possible Injury No.	Possible Injury %	Non-Incapacitating Injury No.	Non-Incapacitating Injury %	Incapacitating Injury No.	Incapacitating Injury %	Fatal No.	Fatal %	Total	% Fatal or Incapacitating Injury
Single Structures	Undivided	1	<18'	-	3	50.0	2	33.3	1	16.7	0	0.0	0	0.0	6	0.0
			>18'	-	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	N/A
		2	<18', <Approach	-	21	77.8	1	3.7	2	7.4	2	7.4	1	3.7	27	11.1
			<18', >Approach	-	1	50.0	0	0.0	1	50.0	0	0.0	0	0.0	2	0.0
			18'-20', <Approach	-	123	71.1	17	9.8	20	11.6	10	5.8	2	1.2	173	7.0
			18'-20', >Approach	-	30	93.8	0	0.0	1	3.1	0	0.0	1	3.1	32	3.1
			20'-22', <Approach	-	171	67.1	33	12.9	28	11.0	15	5.9	8	3.1	255	9.0
			20'-22', >Approach	-	17	63.0	3	11.1	5	18.5	1	3.7	1	3.7	27	7.4
			22'-24', <Approach	-	430	64.3	74	11.1	93	13.9	52	7.8	19	2.8	669	10.6
			22'-24', >Approach	-	155	71.8	21	9.7	23	10.6	14	6.5	3	1.4	216	7.9
			>24'	>50%	782	65.8	151	12.7	157	13.2	81	6.8	16	1.3	1188	8.1
			>24'	1-50%	475	66.2	91	12.7	90	12.5	44	6.1	18	2.5	718	8.6
			>24'	None	863	68.2	138	10.9	136	10.7	97	7.7	32	2.5	1266	10.2
		4	N/A	>50%	221	73.4	29	9.6	33	11.0	14	4.7	4	1.3	301	6.0
				1-50%	58	68.2	16	18.8	7	8.2	3	3.5	0	0.0	85	3.5
				None	658	76.9	91	10.6	65	7.6	31	3.6	11	1.3	856	4.9
	Divided	4	N/A	>50%	350	76.6	53	11.6	37	8.1	12	2.6	5	1.1	457	3.7
				1-50%	164	72.6	28	12.4	23	10.2	8	3.5	3	1.3	226	4.8
				None	84	73.0	14	12.2	15	13.0	1	0.9	1	0.9	115	1.8
		Other	N/A	>50%	716	78.4	112	12.3	66	7.2	17	1.9	2	0.2	913	2.1
				1-50%	77	77.0	12	12.0	7	7.0	3	3.0	1	1.0	100	4.0
				None	277	73.9	51	13.6	34	9.1	12	3.2	1	0.3	375	3.5
Twin Structures	Divided	2	<24'	-	46	82.1	5	8.9	3	5.4	2	3.6	0	0.0	56	3.6
			>24'	>50%	559	69.4	121	15.0	88	10.9	33	4.1	5	0.6	806	4.7
			>24'	1-50%	349	71.5	66	13.5	54	11.1	14	2.9	5	1.0	488	3.9
			>24'	None	795	71.1	127	11.4	128	11.4	60	5.4	8	0.7	1118	6.1
		Other	N/A	>50%	57	63.3	17	18.9	12	13.3	3	3.3	1	1.1	90	4.4
				1-50%	168	73.0	40	17.4	20	8.7	2	0.9	0	0.0	230	0.9
				None	412	65.1	128	20.2	66	10.4	25	3.9	2	0.3	633	4.2
TOTAL					8062	70.5	1441	12.6	1215	10.6	556	4.9	150	1.3	11428	6.2

has any effect on accident severity within each lane strata. The results are presented in the following paragraphs.

3.4.1 One-Lane Bridges

One-lane bridges with curb-to-curb width greater than 18 feet have significantly higher accident severity than those less than or equal to 18 feet. However, the number of accidents is too small to attach much significance to the results.

3.4.2 Two-Lane Undivided Single Structures

For single vehicle accidents, bridges with widths between 22 and 24 feet and greater than approach width have a significantly higher severity than the other bridge narrowness strata, which resulted in significance on the chi-square test. Otherwise, the various bridge narrowness strata have similar accident severity. The reason for such higher severity can be traced to the unusually high percentage (19.3%) of impacts with bridge end/pier for this stratum, while the average for all two-lane undivided single structures is only 8.7 percent (see Tables A.31 and A.28, respectively). There is no apparent explanation for this unusually high percentage of bridge end/pier impacts. This could be the result of unusual site characteristics on bridges within this narrowness strata or possibly just a random fluctuation in the data. Other than this inexplainable occurrence, there appears to be no significant difference in accident severity between the various bridge narrowness strata.

For multi-vehicle accidents, the accident severity for all bridge narrowness strata is similar, and the result of the chi-square test is not significant.

3.4.3 Four-Lane Undivided Single Structures

The results of the chi-square tests are not significant for single vehicle, multi-vehicle, or total accidents, indicating similar accident severity for all bridge narrowness strata.

3.4.4 Four-Lane Divided Single Structures

Again, the accident severity for single vehicle, multi-vehicle, and total accidents is similar for all bridge narrowness strata.

3.4.5 Other Divided Single Structures

The results of the chi-square tests indicate that there is no significant difference between the various bridge narrowness strata for single vehicle, multi-vehicle, and total accidents.

3.4.6 Four-Lane Twin Structures

Marginally significant results were obtained from the chi-square tests on single vehicle accidents, showing that bridges with greater than 50 percent shoulder reduction have slightly higher accident severity while those with 1-50 percent shoulder reduction have slightly lower accident severity. However, the accident severity for multi-vehicle accidents is not significantly different between the various bridge narrowness strata. Total accidents, on the other hand, show a more significant difference in higher accident severity for bridges with greater than 50 percent shoulder reduction and lower accident severity for bridges with 1-50 percent shoulder reduction.

3.4.7 Other Twin Structures

Again, bridges with greater than 50 percent shoulder reduction show a higher accident severity while those with 1-50 percent shoulder reduction have a lower accident severity for single vehicle and multi-vehicle, as well as for total accidents.

3.5 Summary

This chapter has been concerned with defining the extent of the narrow bridge problem, as determined primarily from analyses of the POPULATION file. Of interest have been evaluations of accident rates and accident severities. Summaries of the pertinent findings follow.

It should be noted that, due to a lack of information on the presence/absence of shoulders and their widths in the POPULATION file, various assumptions based on current design standards were made in determining the narrowness categories of the bridges. Since the analyses presented in this chapter are based on comparisons between various narrowness categories, any inaccuracies associated with the determination of narrowness categories could also effect the analysis results, even though the amount of error introduced would likely be minor and should not affect the validity of the results.

- Bridge-related accident rates are significantly higher than average for all road types. Bridge-related non-fatal injury accident rates are also higher than average for interstates and rural arterials and collectors, but lower for urban arterials and collectors. It can be concluded that a safety problem does exist with bridges in general, particularly with interstates and rural highways.

- Accident frequencies are higher on urban bridges than on rural bridges due to higher traffic volume in urban areas. However, once traffic exposure is taken into account, the accident rates are higher on rural bridges than on urban bridges.

- Accident frequencies decline with lower highway types while accident rates increase, again reflecting the effect of traffic exposure. Interstate bridges have the highest accident frequencies but the lowest accident rates. Conversely, bridges on collectors have the lowest accident frequencies but the highest accident rates.

- Bridge narrowness, as defined in terms of shoulder reduction, has significant effects on accident rates for two-lane undivided single structures and four-lane twin structures and has marginally significant effects for four-lane undivided single structures and twin structures with more than four lanes. However, bridge narrowness has no significant effect on accident rates for one-lane bridges and all divided single structures.

- Shoulder reduction seems to have some effect on accident severity for twin structures, with higher accident severity for bridges with greater than 50 percent shoulder reduction, but lower for bridges with 1-50 percent shoulder reduction. However, bridge narrowness appears to have no effect on accident severity for all single structures with the exception of one-lane bridges whose sample size is too small to attach much significance to the results.

CHAPTER IV. ACCIDENT FILE

4.1 Introduction

To provide insights or trends into accident details that are unavailable from police level accident data, such as impact speed, vehicle kinematics, damages to bridge hardware, and detailed vehicle damage and occupant injury severity, an ACCIDENT data file was created. The basis for this file was a total of 125 bridge accidents that were studied in-depth through on-site investigations. This chapter discusses the development of the file, and presents some descriptive statistics and analysis results on the investigated accidents.

4.2 Creation of ACCIDENT File

4.2.1 Sampling Scheme

In order to obtain the required number of 125 accidents within the planned 12-month period, a sampling scheme was formulated to select both fatal and non-fatal bridge accidents for study. As shown in Figure 9, fatal accidents were investigated from the 41-county area around San Antonio while non-fatal accidents were sampled only from the immediate 15-county area.

The sampling scheme was not designed to select accidents that are representative of the accident population as contained in the POPULATION file. Instead, the emphasis was placed on fatal accidents, including both single and multi-vehicle impacts that occurred within the bridge and approach areas, and non-fatal single vehicle collisions involving bridge rail, bridge end, or approach guardrail. For an accident to be eligible, the following criteria had to be met:

Environment Criteria

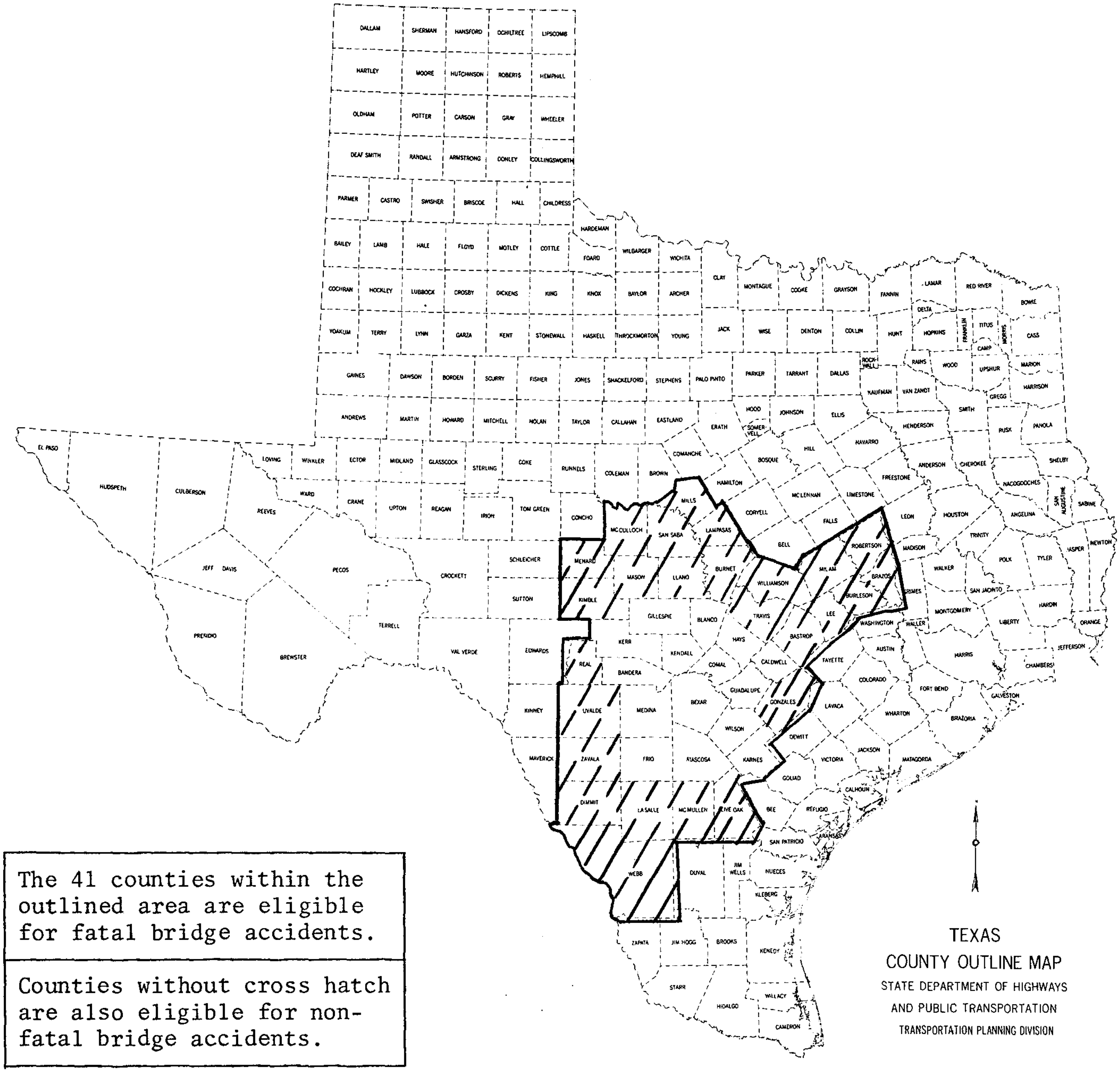
1. The accident must have occurred within 500 ft. of an eligible bridge on an Interstate, U.S., State, Farm to Market or Ranch to Market road.

2. There cannot be a signalized intersection within 500 ft. of the bridge approach.

3. Accidents that occur on access, service, frontage roads, ramps, or interchanges are not eligible.

Vehicle Criteria

1. All involved vehicles in the accident must be passenger cars.



The 41 counties within the outlined area are eligible for fatal bridge accidents.

Counties without cross hatch are also eligible for non-fatal bridge accidents.

FIGURE 9. STUDY AREA FOR BRIDGE ACCIDENT INVESTIGATIONS

2. At least one of the passenger cars must be towed from the scene.

3. In non-fatal accidents the first impact to the passenger car must involve a bridge rail, bridge end, or approach guardrail. The passenger car can then roll over, strike another passenger car, etc.

4. In fatal accidents it is not necessary that the passenger car(s) impact a bridge rail, bridge end, or approach rail; however, the environment criteria must be met.

Other Criteria

1. The accident scene must be inspected by SwRI within 60 hours after occurrence of the accident.

These eligibility criteria turned out to be more restrictive than originally anticipated and it took nearly 21 months (from May, 1979, to January, 1981) before the required 125 accident cases were investigated. Also, only one fatal multi-vehicle accident met the study criteria. The remaining 124 cases were all single vehicle collisions in which there was one or more fatalities or the first impact was with a bridge rail, bridge end, or approach guardrail.

4.2.2 Accident Investigations

Appropriate officials of the San Antonio Police Department and the Texas Department of Public Safety were contacted to set up a notification system. As they designated, either the investigating officer or the dispatcher notified SwRI of possible eligible bridge accidents. Notification of the accident was through a collect telephone call to a member of the SwRI accident investigation team. During working hours, a team member took the call. During other hours, a security guard at the Institute took the information and contacted a team member who returned the call within 30 minutes.

Upon notification, the team member solicited the following information in the preliminary telephone call:

1. Location of bridge accident
2. Time of accident
3. Number and type of involved vehicle(s)
4. Where involved vehicle(s) was towed
5. Name/address of involved driver(s)
6. Telephone numbers of driver(s), if available

7. Hospital where occupant(s) was treated for injuries, if appropriate

8. Name of investigating officer

9. How/where investigating officer can be contacted (phone number preferred).

On determining that an accident was eligible, the investigative team member then performed the following operations:

1. Obtain a copy of the accident report

2. Inspect and document the accident scene

3. Inspect the involved vehicle(s)

4. Interview the involved driver(s)

5. Obtain medical information on injuries sustained by the involved occupant(s).

Information obtained from these accident investigations was recorded on field data forms, including standard forms from the National Accident Sampling System (NASS): accident form, vehicle form, driver form, and occupant form. In addition, two supplementary forms were used for detailed environmental and bridge data--one on inventory data elements and one on scene data elements.

4.2.3 Accident Reconstructions

The CRASH3* computer program normally used for accident reconstructions is not adequate for accidents involving impact with longitudinal barriers (guardrails, bridge rails, median barriers) that were of interest in this study. Originally, it was planned to use the BARRIER VII computer program for these reconstructions. However, this program requires a great deal of barrier and vehicle inputs. A test case of several BARRIER VII runs was made in which the various inputs were parametrically changed and the resulting vehicle trajectories were compared with the actual trajectory of the accident. Additionally, a manual reconstruction was made in which CRASH3 was used to estimate the energy of vehicle deformation and linear momentum principles were used for the frictional energy loss of the vehicle/barrier contact.

The best of the BARRIER VII runs and the manual reconstruction agreed quite well for vehicle speeds. Because of the complexity of the BARRIER VII inputs and coding with the associated added expense and time,

---

* Calspan Reconstruction of Accident Speeds on the Highway, Version 3.

it was recommended and approved that the manual procedure be used for the remaining accident reconstructions. A small computer program was prepared to make the calculations. Details of the analytical formulation and the computer program listing and sample run are contained in Appendix G.

4.2.4 ACCIDENT File Layout and Format

Data for each accident in the ACCIDENT file is contained in 26 cards as follow:

- Accident Form - 1 card
- Vehicle Form - 3 cards
- Driver Form - 1 card
- Occupant Form - 10 cards
- Inventory Data Elements - 7 cards
- Environmental Scene - 4 cards

As indicated in Section 4.2.2 above, the first four of these forms are standard NASS forms and the remaining two are supplementary environmental forms. The occupant form generates two records (cards) for each occupant up to a maximum of five occupants. However, to maintain a constant record length, all ten cards are used for each case. For example, if two occupants are in the vehicle, four records contain their information and six records are left blank.

An ACCIDENT SUMMARY file was then created for analysis purposes. Details of the format and data element codes for the ACCIDENT and ACCIDENT SUMMARY files are contained in Appendix H.

4.3 General Accident Characteristics

As previously pointed out under Section 4.2.1, only one of the 125 accidents investigated in depth in this study turned out to be a multi-vehicle accident. The eligibility criteria allow the sampling of a multi-vehicle accident only if the accident resulted in one or more fatalities. As it turned out, there was only one such multi-vehicle fatal accident sampled in the study. The other 124 remaining cases were all single vehicle collisions in which there was one or more fatalities or the first impact was with a bridge rail, bridge end, or approach guardrail. With only one multi-vehicle accident, it was not worthwhile to design the file setup to include both single and multi-vehicle accidents. Thus, only the 124 single vehicle accidents are included in the data file. Selected statistical tables describing these accidents are contained in Appendix I. This section contains salient points of the descriptive statistics for general accident characteristics.

4.3.1 Accident Type

Tables A.37 through A.39 describe the first harmful event, its location in relation to the roadway, and its location in relation to the bridge. Of the first objects struck, 25.8 percent are bridge rails, 4.0 percent bridge rail/parapet end, 21.8 percent guardrails, 15.3 percent guardrail transition or end, 22.6 percent median barriers, and 10.5 percent other objects. Most of the accidents occur on the shoulder (38.7%), in the median (30.7%), and on the roadside (26.6%). Over half (52.4%) of the accidents occur on the approach to the bridge with 8.9 percent in the transition area. Approximately one-third (32.3%) of the accidents occur on the bridge itself and another 11.3 percent on the approach away from the bridge.

4.3.2 Environmental Data

Tables A.40 through A.49 and Figures A.12 and A.13 contain environmental data for the 124 accidents, including some geometric information. Notable features follow:

- Only 35.5 percent of the accidents occur under daylight conditions with another 2.4 percent during dawn or dusk hours. The remaining 62.1 percent of the accidents occur during darkness of which 39.5 percent are under lighted conditions.

- The highest accident occurrence is on Sunday (21.0%), followed by Saturday (16.9%), while the lowest occurrence is on Monday (10.5%).

- The distribution of accidents by hours of the day reflects the predominance of accidents during the hours of darkness, especially between 9:00 p.m. to 4:00 a.m. In general, the time of occurrence distribution of accidents on bridges and their approaches is very similar to that of all single-vehicle accidents with highest occurrence on weekends and during late night and early morning hours.

- Adverse driving conditions, such as rain and wet pavement, do not appear to have any significant impact on accident occurrence, accounting for only 13.7 percent of the accidents.

- The majority (66.1%) of the accidents investigated occur on urban interstate highways, with rural major arterials (11.3%) a distant second. Overall, 75.8 percent of the accidents are in urban areas, reflecting the predominantly urban nature of the study area.

- Only 22.6 percent of the accidents occur on roadways with no access control. The majority of the bridges on which the accidents occur have two (53.2%) or three (33.1%) approach lanes.

- Over half (54.0%) of the accident bridges have straight horizontal alignment for both the bridges and their approaches. Another 16.1 percent of the accident bridges are straight on the bridge itself, but with curved approaches. This reflects the preference to design briges with straight alignment for ease of design and construction. Also, the degree of curvature on the bridge is generally less than that of the approach.

- The majority of accident bridges are level (52.4%) or with a slight upgrade (37.8%) in the direction of vehicle travel. The grades are rather gentle with a maximum of 4 percent downgrade and 6 percent upgrade.

- Over half (54.5%) of the approaches to bridges are upgrades in the direction of vehicle travel, reflecting the approaches to overpass structures. Another 26.0 percent of the accidents occur on bridges with level approaches. Again, the grades are rather gentle with only 5.7 percent of the grades in excess of 4 percent upgrade or downgrade. Overall, the horizontal and vertical alignments for the approaches are very gentle and do not appear to have much effect on accident occurence.

- With the relatively gentle horizontal and vertical alignment on the bridges and their approaches, the minimum sight distance approaching the bridge is over 400 feet with only three accidents reporting the presence of some form of vision obstruction.

- The traffic volume distribution reflects that of the roadway functional classification over half (55.5%) of the accident locations have ADT in excess of 35,000 vehicles per day, which is expected given the predominance of urban interstate highways.

- Sixty percent of the accident bridges have between 6 to 10 percent of trucks in the traffic mix with another 24.5 percent having a traffic mix of over 10 percent trucks.

4.3.3 General Vehicle Data

It should be recalled that only passenger cars were eligible for this study and the results should therefore be viewed accordingly. The model year of the vehicles ranges from 1962 to 1980 and the average age of the vehicles is approximately six years.

The vehicles are fairly evenly distributed between mini/subcompact (19.4%), compact (27.4%), intermediate (29.8%) and standard/luxury (23.4%) sizes, as shown in Table A.50. As for vehicle curb weight, the majority (71.8%) range from 3,000 to 4,500 pounds, as shown in Table A.51. Another 20.1 percent of the vehicles have curb weights less than 3,000 pounds while only 8 percent are over 4,500 pounds, reflecting the current downsizing trend of the vehicle fleet.

Descriptive statistics pertaining to vehicle damages resulting from barrier impacts are included in Tables A.52 through A.55. For the first barrier impact, over three-quarters (76.6%) of the vehicles sustained 11, 12 or one-o'clock direction of force with 12 o'clock alone accounting for 54.1 percent, as shown graphically in Figure 10. Directions of force between 3 and 9 o'clock constitute only 7.2 percent of the impacts. The percentage of force directions between 11 and one o'clock direction of force decreases to 50.7 percent for the second and 47.4 percent for the third barrier impacts. Conversely, directions of force between 3 and 9 o'clock increase drastically to 30.2 percent for the second and 36.8 percent for the third barrier impacts. This indicates that the impacting vehicles are more likely to be yawing or rotating in subsequent barrier impacts.

As indicated by the direction of force, the front of the vehicle accounts for the majority (74.8%) of the first barrier impact, decreasing to 44.4 and 30.0 percent for the second and third barrier impacts, respectively. At the same time, the involvement of the side and back of the vehicle increases drastically for subsequent barrier impacts. The majority of vehicle damage distribution resulting from barrier impacts is wide (59.0% to 63.2%) with the remainder mostly corner impacts or of a sideswipe nature (30.6% to 36.9%).

The vehicle damage extent from barrier impacts is mostly very minor with extent codes of one or two in the majority of the cases (71.2%, 67.7% and 54.5% for the first, second, and third barrier impacts, respectively). High damage extent codes of 8 and 9 pertain to sideswipes and the trend of increasing occurrences of sideswipes in subsequent barrier impacts is again evident with 16.1 percent for the first barrier impact, increasing to 19.1 percent and 22.7 percent for the third barrier impacts.

Information regarding vehicle damage characteristics for the most severe impact is also present in Tables A.52 through A.55. More detailed discussion will be presented in Section 4.5.2 in conjunction with injury severity.

4.3.4 General Occupant Data

Information pertaining to general occupant data is shown in Tables A.56 through A.59. The majority (70.2%) of the vehicles have only a single

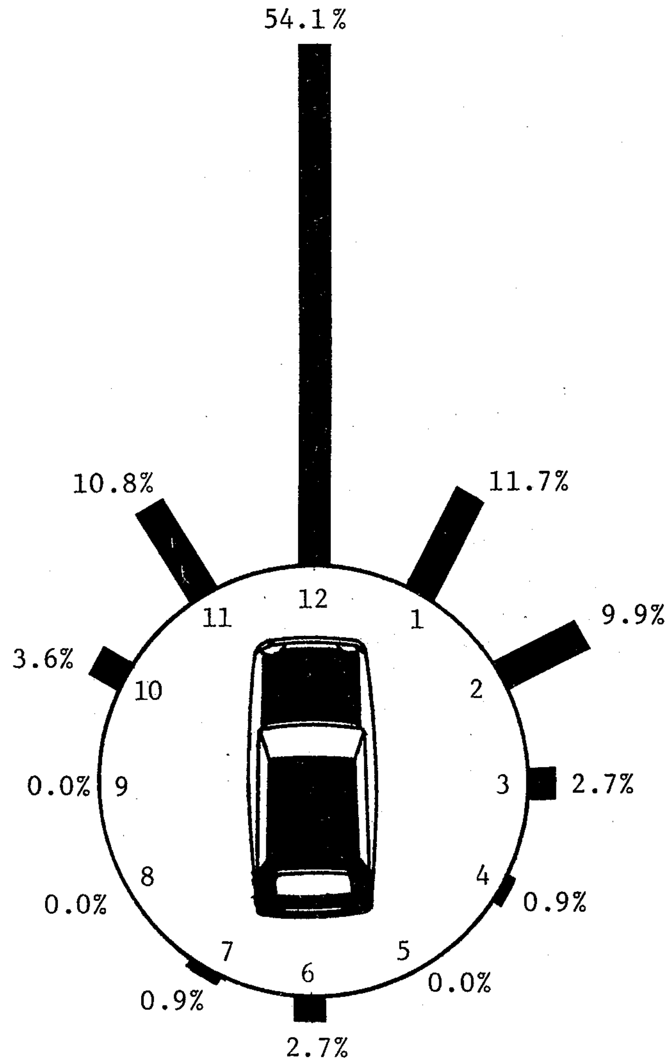


FIGURE 10. DISTRIBUTION OF VEHICLE DAMAGE BY DIRECTION OF FORCE FOR FIRST BARRIER IMPACT*

* Note. There are three cases (2.7%) with non-horizontal direction of force (00).

Site familiarity ?

occupant with another 14.9 percent containing two occupants and the remainder with three or more occupants. The drivers are mostly male (70.8%) and 25 years of age or younger (50.8%).

Over 70 percent of the drivers received some form of injury (AIS* $\geq$ 1) though only 14.2 percent received severe to fatal injuries of AIS $\geq$ 3. As for the highest occupant injury, 83.1 percent are accounted for by the drivers, including 70.2 percent in which the driver is the only occupant. Another 12.9 percent are front seat passengers and the remaining 4.0 percent are rear seat passengers. As expected, the highest occupant injury is more severe than driver injury with 75.6 percent receiving some form of injury and 18.4 percent severe to fatal injuries.

Restraint usage is very low with only 11 percent of the drivers wearing a lap belt (3.4%) or lap belt and shoulder harness (7.6%). As for the occupant receiving the highest injury severity, the restraint usage rate is even lower with 2.5 percent for lap belt and 5.9 percent for lap belt and shoulder harness.

Table A.60 shows a comparison between injury severity by the Abbreviated Injury Scale (AIS) and the Police Injury Code (PIC). The PIC code of A (incapacitating injury) has the widest scatter, ranging from AIS levels of 1 to 5. The other PIC codes closely reflect those of AIS. The results of this comparison are consistent with those from other studies, such as the National Accident Sampling System.

4.4 Specific Accident Characteristics

This section contains salient features of the descriptive statistics for specific accident characteristics.

4.4.1 Impact Sequence

Tables 20 through 22 summarize the total number of impacts in the accidents, and the location and object contacted in the first impact. Over three-quarters (77.4%) of the accidents involve more than one impact, half of which are three or more impacts. This indicates the importance of subsequent impacts as a factor in the evaluation of barrier performance.

---

* AIS - Abbreviated Injury Scale: 0 = no injury, 1 = minor injury, 2 = moderate injury, 3 = severe injury, 4 = serious injury, 5 = critical injury, 6 = maximum (untreatable). The remaining codes of: 7 = injured, severity unknown and 9 = unknown if injured, are used for unknown injury severity.

TABLE 20

TOTAL NUMBER OF IMPACTS

Total Number of Impacts	Frequency	Percent
1	28	22.6
2	48	38.7
3	27	21.8
4	18	14.5
5	2	1.6
6	1	0.8
Total	124	100.0

TABLE 21

LOCATION OF FIRST IMPACT

Location	Number	Percent
Approach 1	54	43.5
Transition - Approach 1 to Bridge	11	8.9
Bridge	40	32.3
Transition - Bridge to Approach 2	1	0.8
Approach 2	13	10.5
Other	5	4.0
Total	124	100.0

TABLE 22

OBJECT CONTACTED IN FIRST IMPACT

Object Contacted	Number	Percent
Bridge Rail	32	25.8
Bridge Rail/Parapet End	8	6.5
Guardrail	25	20.2
Guardrail End	11	8.9
Guardrail Transition	5	4.0
Median Barrier	29	23.4
Other Object	14	11.3
Total	124	100.0

The majority of the first impacts (52.4%) occurred in the approach to the bridge (Approach 1) or in the transition from Approach 1 to the bridge. Another 32.3 percent of the first impacts occurred on the bridge itself and only 11.3 percent occurred in the approach away from the bridge (Approach 2) or in the transition from the bridge to Approach 2. As for object contacted in the first impact, bridge rail accounts for 25.8 percent of the impacts, with bridge rail/parapet end another 6.5 pecent. Guardrail and median barrier account for the majority (56.5%) of the first impacts, 12.9 percent of which involve guardrail end or transition sections.

Detailed tabulations of the location and object contacted for the first four impacts are shown in Tables A.61 and A.62, respectively. More detailed discussions on subsequent impacts will be presented later in this section.

4.4.2 Encroachment Characteristics

Tables A.63 through A.67 contain statistics of the vehicle as it departed from the roadway and prior to the first impact. Right and left vehicle runoffs are almost equal, with 44.5 percent on the right-hand side of the roadway, 38.7 percent on the left of divided roads with objects struck in the median, 8.4 percent on the left of one-way roadways, and 5.9 percent on the left of two-way roadways.

The majority (61.6%) of the departure angles are 15 degrees or less with another 24.8 percent between 16 and 25 degrees. The overall average departure angle is 14.6 degrees, while the median departure angle is smaller at 12.2 degrees. The departure angle distribution is shown graphically in Figure 11 and a gamma function was fitted to the data with good results. Departure speeds between 40 and 70 miles per hour (mph) are predominant (65%) with an overall average of 52.9 mph and a median of 54.3 mph. Again, a gamma function is fitted to the departure speed distribution, as shown in Figure 12. Most (61%) of the vehicles are tracking at departure with another 14.6 pecent yawing at 30 degrees or less. The distance travelled from departure to first impact is usually very short with only 22.6 percent travelling more than 50 feet.

It should be noted that the departure or encroachment characteristics described above pertain mainly to interstate highways and expressways where the speed limit is 55 mph and the operating speeds are generally even higher than the speed limit during off-peak hours. It appears that there is little braking prior to departure for most of the accident vehicles.

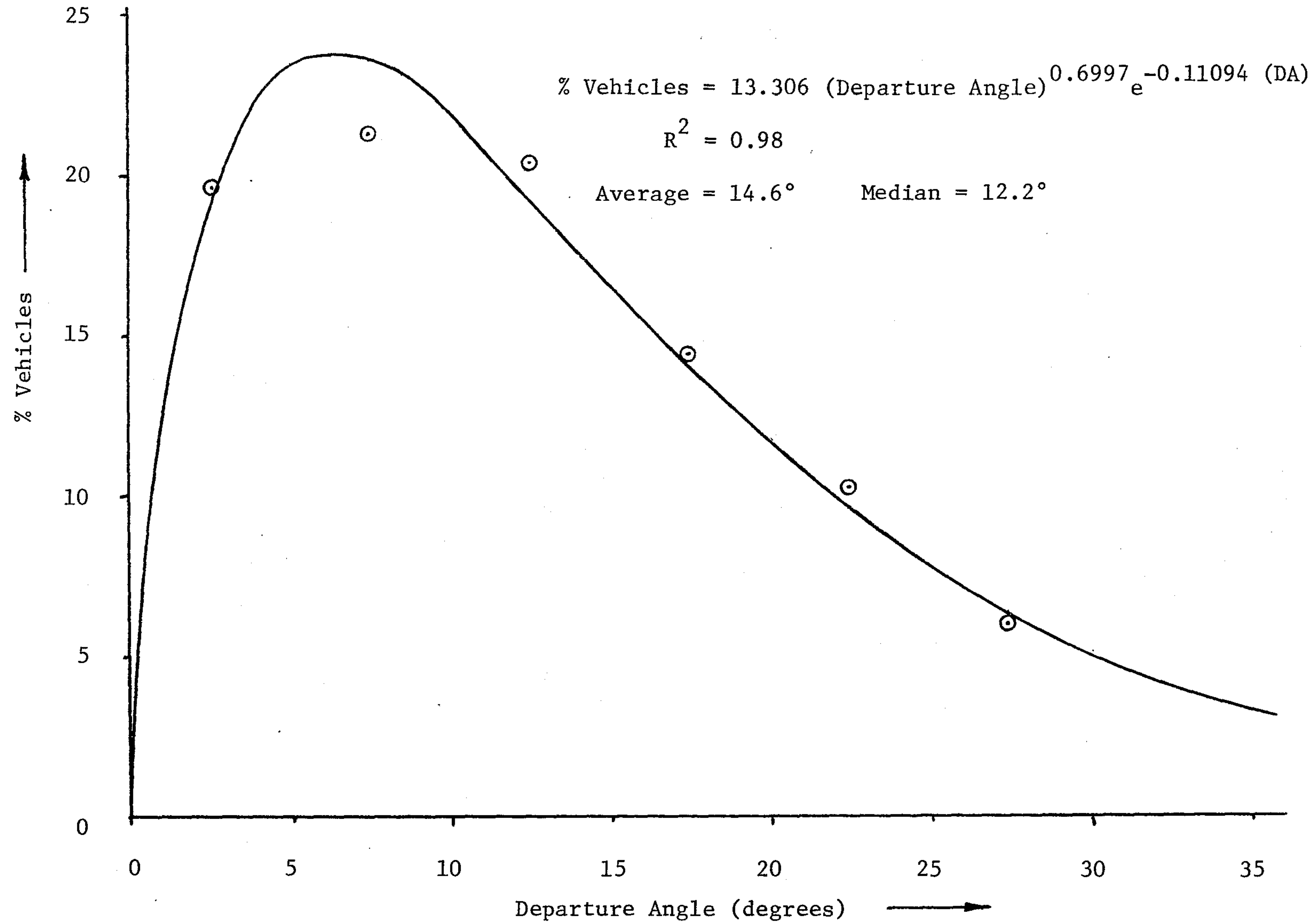


FIGURE 11. DISTRIBUTION OF DEPARTURE ANGLES

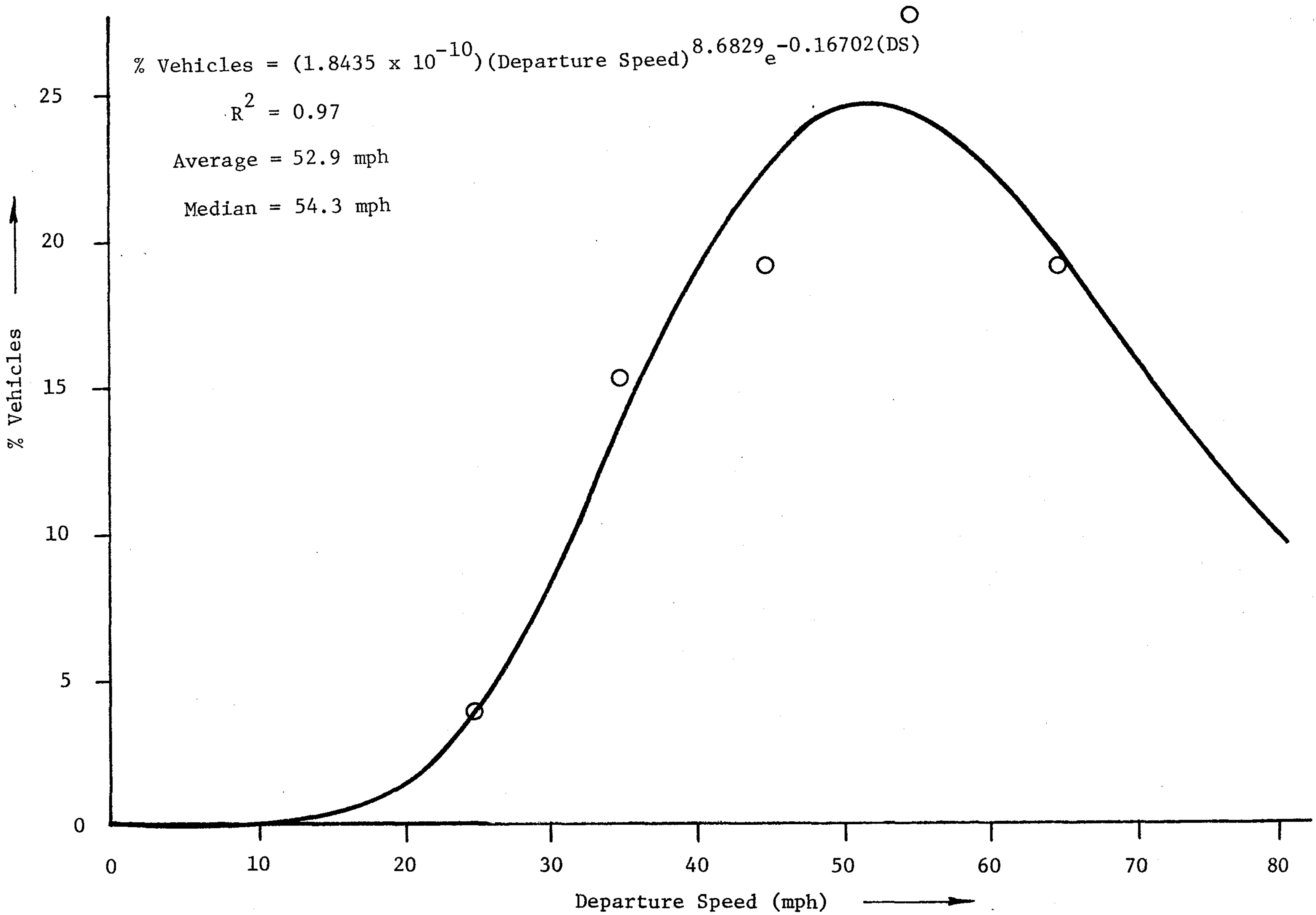


FIGURE 12. DISTRIBUTION OF DEPARTURE SPEEDS

4.4.3 Impact Conditions

Tables A.68 through A.71 contain information about the impact phase of the accidents for the first three barrier impacts. As expected, the impact angle increases and the impact speed decreases with subsequent impacts. For example, the average impact angle is 14.4 degrees for the first barrier impact with an average impact speed of 50.6 mph. The average impact angle increases to 15.0 degrees for the second barrier impact and further to 17.1 degrees for the third barrier impact. Conversely, the impact speed decreases to 39.2 mph for the second barrier impacts and 30.2 mph for the third barrier impacts.

Most of the vehicles (51.2%) continue tracking from departure to impact, with another 22.8 percent yawing at less than 30 degrees at impact. Furthermore, the percentage of vehicles tracking at impact decreases from 51.2 percent for the first barrier impact to 33.3 percent for the second and 36.8 percent for the third while the percentage for higher yawing angles increases. This indicates that the vehicle trajectories are more abrupt in subsequent impacts although the impact speeds are lower.

The distributions of impact angles and impact speeds for the first barrier impact are shown graphically in Figures 13 and 14. Again, gamma functions are fitted to the data. The distribution of first impact angles by impact speeds is shown in Table 23. A weak trend can be seen of the expected smaller impact angles with the higher impact speeds. Results from this study indicate that the impact conditions currently used in full-scale crash testing of longitudinal barriers, i.e., impact speed of 60 mph and impact angles of 15 and 25 degrees, are good approximations of the average and limiting impact conditions.

Velocity changes from barrier impacts are relatively low compared to the impact speeds. This indicates that the impacting vehicles retain a large proportion of their impact speeds after separating from the barriers and subsequent impacts are also of considerable importance. Figure 15 illustrates the distribution of velocity changes for first barrier impacts. Again, a gamma function is fitted to the data. Over one-third (34.6%) of the velocity changes are 10 mph or less with another 42.3 percent between 11 and 30 mph.

Tables A.72 and A.73 include information concerning the extent of damage to the barrier. Most of the damages to the barriers are relatively

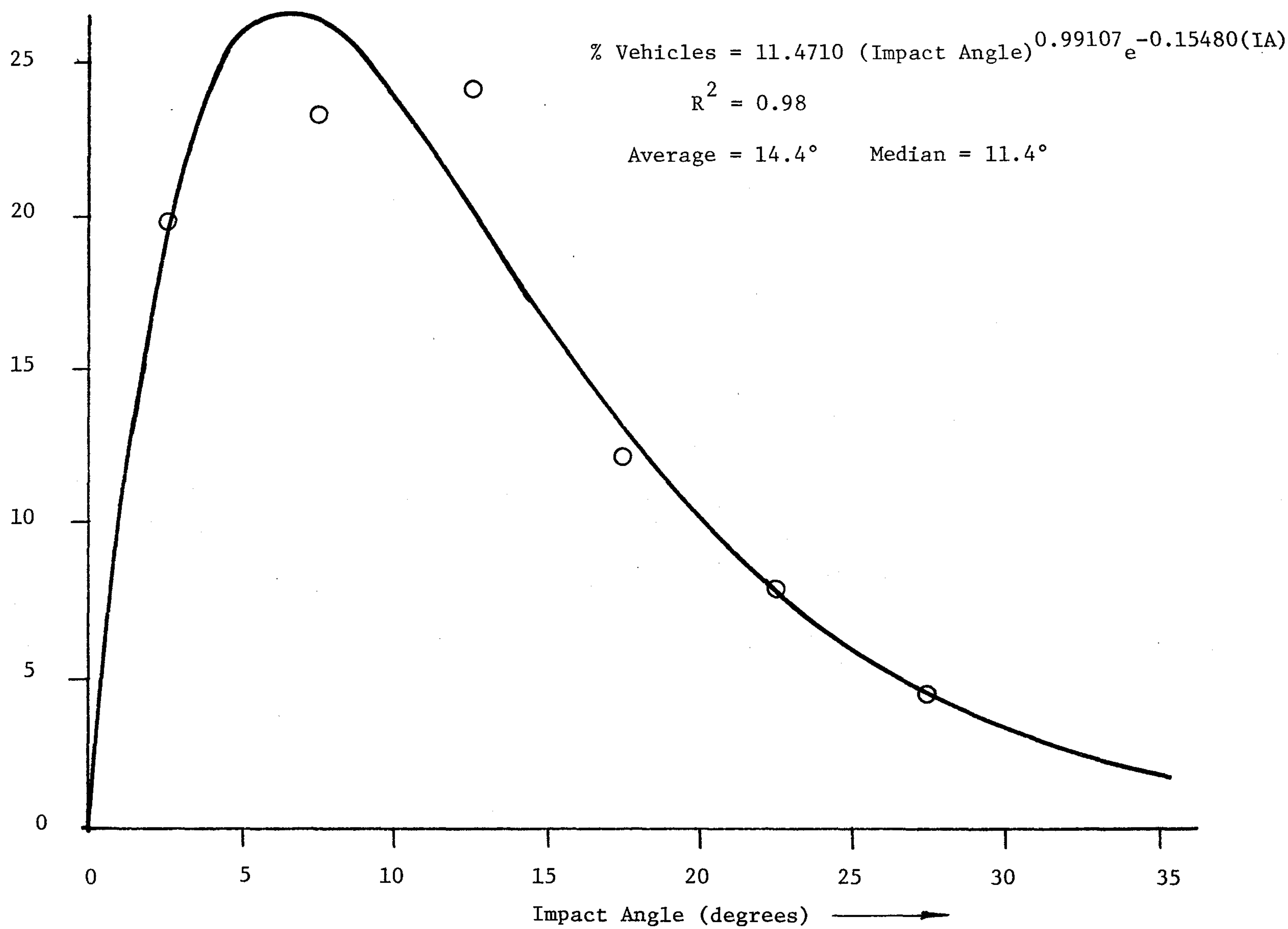


FIGURE 13. DISTRIBUTION OF IMPACT ANGLES FOR FIRST BARRIER IMPACT

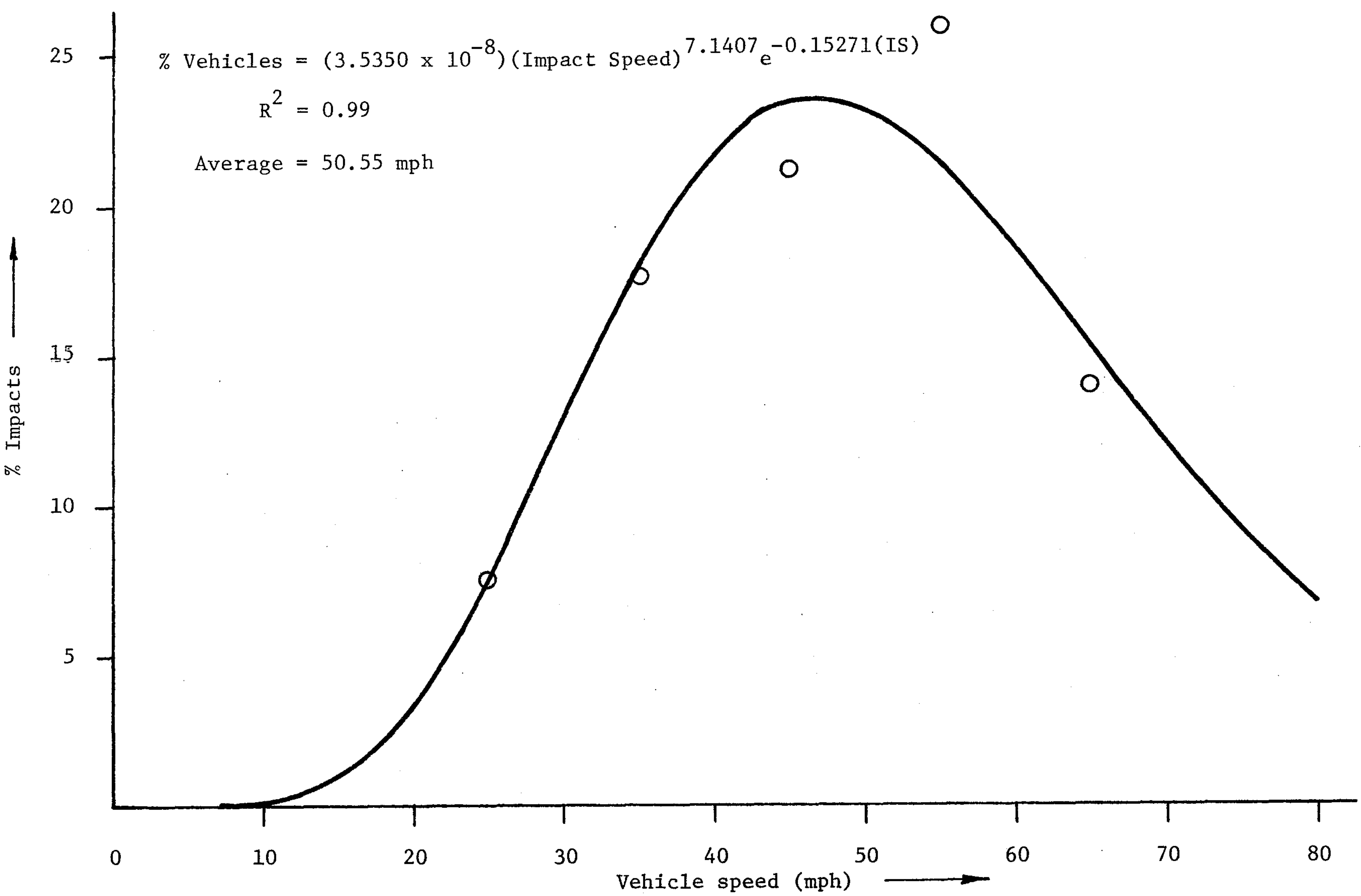


FIGURE 14. DISTRIBUTION OF IMPACT SPEEDS FOR FIRST BARRIER IMPACT

TABLE 23

DISTRIBUTION OF IMPACT ANGLES BY IMPACT SPEEDS FOR FIRST BARRIER IMPACT

Impact Speed (mph)	Impact Angle (degrees) 1-5 No.	%	6-10 No.	%	11-15 No.	%	16-20 No.	%	21-25 No.	%	26-30 No.	%	> 30 No.	%	TOTAL
≤ 30	2	22.2	3	33.3	2	22.2	0	0.0	0	0.0	1	11.1	1	11.1	9
31-40	1	5.6	2	11.1	7	38.9	2	11.1	3	16.7	2	11.1	1	5.6	18
41-50	3	13.0	4	17.4	5	21.7	8	34.8	1	4.3	0	0.0	2	8.7	23
51-60	6	23.1	6	23.1	8	30.8	1	3.8	0	0.0	1	3.8	4	15.4	26
61-70	4	26.7	5	33.3	2	13.3	1	6.7	2	13.3	1	6.7	0	0.0	15
> 70	5	38.5	2	15.4	3	23.1	1	7.7	2	15.4	0	0.0	0	0.0	13
TOTAL	21	20.2	22	21.2	27	26.0	13	12.5	8	7.7	5	4.8	8	7.7	104

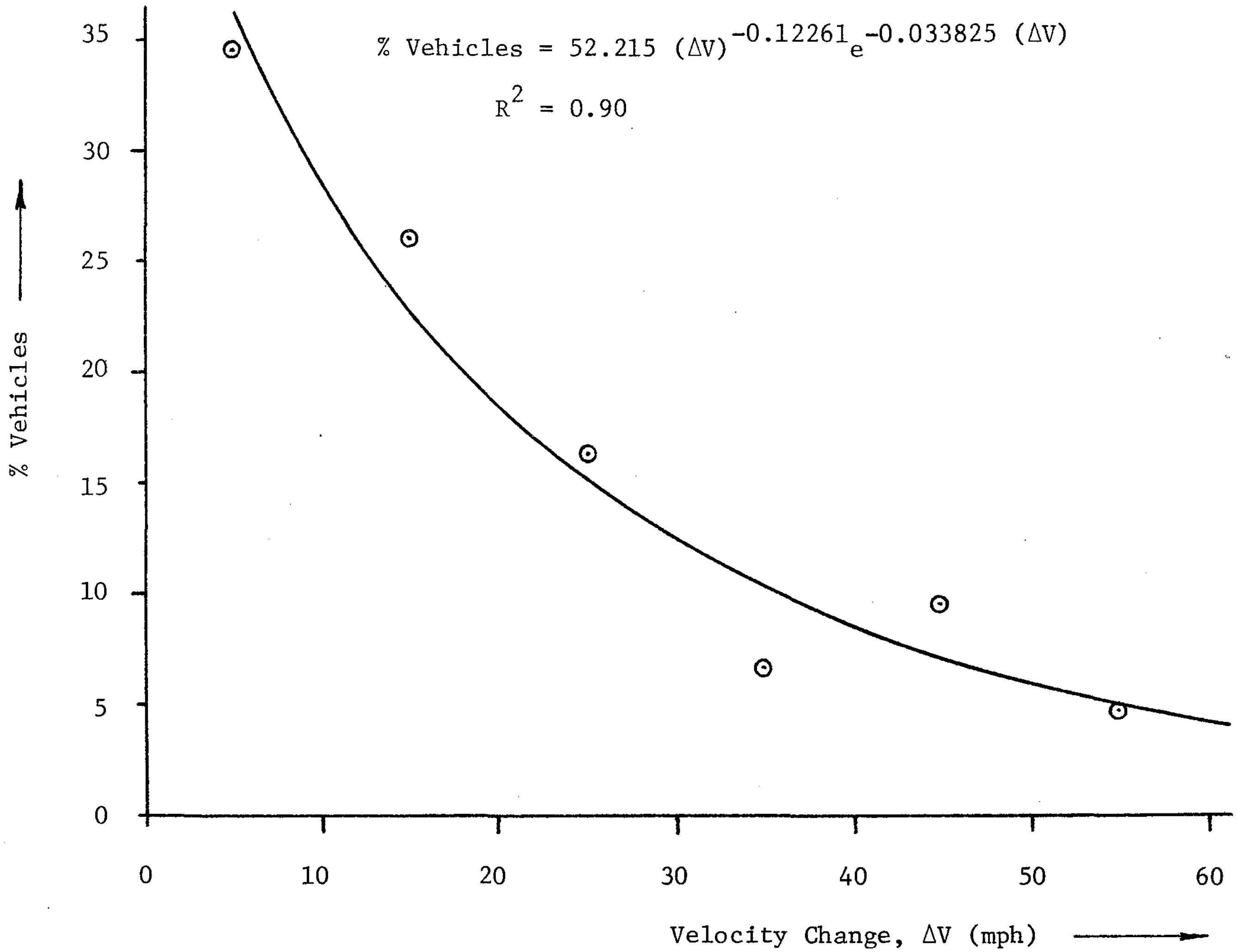


FIGURE 15. DISTRIBUTION OF VELOCITY CHANGE FOR FIRST BARRIER IMPACT

minor with length of deformation 50 feet or shorter in over 85 percent of the cases and only three percent longer than 100 feet. Over 58 percent of the depth of barrier deformation is less than six inches with another 30 percent between six and eighteen inches.

4.4.4 Separation Conditions

Table 24 summarizes the barrier performance and Table A.74 illustrates the distribution of separation angles for the first three barrier impacts. For the first barrier impact, 22.7 percent of the impacts resulted in improper performance by the barrier, including overriding (10.1%), vaulting (8.4%) and penetration (4.2%). The impacting vehicle is redirected in 73.1 percent of the impacts, including situations where the vehicle came to rest against the barrier with no separation (10.9%). For vehicles that are separated from the barrier, the separation angle is mostly very gentle with 15 degrees or less in over 80 percent of the separations.

For second and third barrier impacts, the percentage of improper performance remains in the neighborhood of 20 percent though the severity is much less with fewer occurrences of vaulting and penetration. This reflects the lower impact speeds of the subsequent impacts and hence the lower severity. The percentage of no separation in subsequent impacts doubles that of the first barrier impact, again reflecting the lower impact speeds. However, the distributions of separation angles for vehicles that separate from the barrier are similar between the various impacts with slight increases in the separation angles for subsequent impacts.

4.4.5 Subsequent Impacts

Table A.75 describes the vehicle trajectory subsequent to the barrier impacts. The post-impact trajectory for the first barrier impact is more severe than the second and third barrier impacts as anticipated with the higher separation speeds. Over one-quarter (26.0%) of the vehicles returned to and crossed the roadway after the first barrier impact and ran the opposite side of the roadway or onto another roadway. Such occurrences decrease to 9.0 percent for the second and 4.8 percent for the third impacts, reflecting the lower separation speeds. However, the percentage of vehicles returning to the roadway did increase for subsequent barrier impacts.

The occurrence and nature of subsequent impacts after the various barrier impacts are summarized in Table 25. As expected, the percentage of no subsequent impact increases drastically from 28.2 percent for the

TABLE 24

BARRIER PERFORMANCE

Barrier Performance	First Barrier Impact No.	First Barrier Impact %	Second Barrier Impact No.	Second Barrier Impact %	Third Barrier Impact No.	Third Barrier Impact %	Total No.	Total %
Vehicle redirected by barrier	87	73.1	53	79.1	16	76.2	156	75.4
Vehicle overrode barrier	12	10.1	9	13.4	5	23.8	26	12.6
Vehicle vaulted barrier	10	8.4	1	1.5	0	0.0	11	5.3
Vehicle penetrated barrier	5	4.2	3	4.5	0	0.0	8	3.9
Other	5	4.2	1	1.5	0	0.0	6	2.9
Unknown	5	--	1	--	1	--	7	--
Total	124	100.0	68	100.0	22	100.0	214	100.0

TABLE 25

SUBSEQUENT IMPACT

Subsequent Impact	First Barrier Impact No.	First Barrier Impact %	Second Barrier Impact No.	Second Barrier Impact %	Third Barrier Impact No.	Third Barrier Impact %	Total No.	Total %
None	35	28.2	38	56.7	16	76.2	89	42.0
Another vehicle	5	4.0	4	6.0	1	4.8	10	4.7
Another roadside structure/object	41	33.1	13	19.4	3	14.3	57	26.9
Same longitudinal barrier	21	16.9	3	4.5	0	0.0	24	11.3
Another longitudinal barrier	13	10.5	4	6.0	0	0.0	17	8.0
Rollover	6	4.8	3	4.5	0	0.0	9	4.2
Other	3	2.4	2	3.0	1	4.8	6	2.8
Unknown/Not Applicable	0	--	1	--	1	--	2	--
Total	124	100.0	68	100.0	22	100.0	214	100.0

first barrier impact to 56.7 percent for the second and 76.2 percent for the third barrier impacts, reflecting the decrease in vehicle speed as it went through the impact sequence.

Nearly half the subsequent impacts are with another roadway structure/ object. For the first barrier impact, 38.2 percent of the subsequent impacts are with the same or another longitudinal barrier. The percentage decreases to 24.1 percent for the second and none for the third barrier impacts. On the other hand, the percentage of subsequent impacts with another vehicle increases for second and third barrier impacts, perhaps as a result of higher occurrences in which the vehicle returned to the roadway for the subsequent impacts. Rollovers and other nonhorizontal impacts constitute a sizeable portion of subsequent impacts, ranging from 10.1 percent for the first barrier impact to 17.2 percent for the second and 20.0 percent for the third barrier impacts.

4.5 Relationships to Injury Severity

This section examines the injury severity of the 124 investigated accidents and their relationships to selected accident characteristics. Highest occupant injury is used throughout this section and is expressed in terms of the Abbreviated Injury Scale (AIS). With a sample size of only 124 accident cases, the extent of statistical analysis is rather limited and is confined to bivariate type of analysis in which the relationships between injury severity and selected accident characteristics can be examined only one at a time.

In fact, the chi-square test is used throughout this section for testing of statistial significance. In order to keep the number of cells to a minimum, injury severity is categorized into only two groups: AIS ≤ 3 (no to moderate injury) and AIS ≥ 3 (severe to fatal injury). For each chi-square test, the chi-square statistic (χ^2), the degrees of freedom (d.f.) and the confidence level (e.g., significant @ 0.01) are given at the bottom of the table. When the confidence level is above 0.15, the test is termed not significant and the confidence level will not be shown.

4.5.1 General Accident Characteristics

Table 26 illustrates the injury severity by total number of impacts. There is a clear and statistically significant trend that the injury severity increases with the total number of impacts. For a single impact accident, 35.7 percent result in no injury and 14.3 percent with AIS ≥ 2. The

TABLE 26

TOTAL NUMBER OF IMPACTS AND INJURY SEVERITY

Total Number of Impacts	Highest Injury Severity (AIS) 0 No.	%	1 No.	%	2 No.	%	≥ 3 No.	%	Total No.	%
1	10	35.7	14	50.0	3	10.7	1	3.6	28	23.9
2	13	29.5	18	40.9	1	2.3	12	27.3	44	37.6
3	4	16.0	13	52.0	6	24.0	2	8.0	25	21.4
≥ 4	2	10.0	10	50.0	1	5.0	7	35.0	20	17.0
Total	29	24.8	55	47.0	11	9.4	22	11.8	117	100.0

$\chi^2 = 11.67$ d.f. = 3 (significant @ 0.01) percentage of no injury decreases with increasing number of impacts to only 10.0 percent for four or more impacts while the percentage of AIS $\geq$ 3 increases to 40.0 percent. This indicates the importance of subsequent impacts for accidents involving barriers.

Table A.76 examines the injury severity by pre-crash travel of the vehicle. The severity of accidents in which the vehicle ran off the right-hand side (RHS) of the roadways is somewhat higher than if the vehicle ran off the left-hand side (LHS) although the result is only marginally significant. The percentage of AIS $\geq$ 3 is 22.4 percent for RHS departures as compared to 11.1 for LHS departures.

The distribution of injury severity by vehicle size and curb weight is shown in Table 27. It is surprising that the data does not reflect the expected trend of increasing injury severity for smaller and lighter vehicles. In fact, the percentage of AIS $\geq$ 3 is highest for full-size vehicle (32.1%) and curb weight of 3,501-4,500 pounds (23.9%) while the corresponding percentage for mini/subcompact vehicle is 13.6 percent and that for vehicles with curb weight of 2,500 pounds or less is 15.4 percent. However, the results are not statistically significant.

As shown in Table 28, accidents in which the vehicle rolled over have much higher injury severity (40.0% AIS $\geq$ 3) than if the vehicle did not roll over (11.6% AIS $\geq$ 3). Higher injury severity also results for vehicles with passenger compartment integrity loss and intrusion, as shown in Table A.77. Chi-square test results are all highly significant. It is believed that passenger compartment integrity loss and intrusion are mostly associated with rollovers and other nonhorizontal impacts.

4.5.2 First Barrier Impact

The relationships between injury severity and selected characteristics of the first barrier impact are presented in this subsection. The average impact speeds and angles for the various AIS levels are summarized in Table 29 while Table A.78 tabulates the actual distribution. As expected, the average impact speed increases with higher injury severity from 47.0 mph for no injury to 60.0 mph for severe to fatal injuries (AIS $\geq$ 3). On the other hand, the injury severity level does not seem to be affected by the impact angle.

To further examine these relationships, injury rates (defined as the percentage of accidents above a certain injury severity, i.e., AIS $\geq$ 1,

TABLE 27

DISTRIBUTION OF INJURY SEVERITY BY VEHICLE SIZE AND WEIGHT

	Highest Injury Severity (AIS)									
	0		1		2		≤ 3		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
VEHICLE SIZE										
Mini/Subcompact	5	22.7	11	50.0	3	13.6	3	13.6	22	18.8
Compact	10	32.3	14	45.2	2	6.5	5	16.1	31	26.5
Intermediate	8	22.2	20	55.6	3	8.3	5	13.9	36	30.8
Full Size	6	21.4	10	35.7	3	10.7	9	32.1	28	23.9
Total	29	24.8	55	47.0	11	9.4	22	18.8	117	100.0

$\chi^2 = 4.36$ d.f. = 3 (Not significant)

	Highest Injury Severity (AIS)									
	0		1		2		≤ 3		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
VEHICLE CURB WEIGHT										
≤ 2,500 lbs	2	15.4	7	53.8	2	15.4	2	15.4	13	11.1
2,501-3,500	16	30.8	23	44.2	5	9.6	8	15.3	52	44.4
3,501-4,500	10	21.7	22	47.8	3	6.5	11	23.9	46	39.3
> 4,500 lbs	1	16.7	3	50.0	1	16.7	1	16.7	6	5.1
Total	29	24.8	55	47.0	11	9.4	22	18.8	117	100.0

$\chi^2 = 1.30$ d.f. = 3 (Not significant)

TABLE 28

ROLLOVER INVOLVEMENT AND INJURY SEVERITY

	Highest Injury Severity (AIS)				Total	
	No to Moderate Injury, AIS ≤ 2		Severe to Fatal Injury, AIS ≥ 3		Total	
Rollover Involvement	No.	%	No.	%	No.	%
Yes	18	60.0	12	40.0	30	25.9
No	76	88.4	10	11.6	86	74.1
Total	94	81.0	22	19.0	116	100.0

$\chi^2 = 11.65$ d.f. = 1 (significant @ 0.001)

TABLE 29

AVERAGE IMPACT SPEED AND ANGLE OF FIRST BARRIER IMPACT
BY HIGHEST INJURY SEVERITY

Injury Severity		Impact Speed (mph)		Impact Angle (degrees)	
AIS	Description	Sample Size	Average	Sample Size	Average
0	None	26	47.0	28	14.1
1	Minor	51	53.6	52	14.1
2	Moderate	10	54.7	11	15.6
3	Severe	7	57.1	8	17.6
4	Serious	6	60.0	6	12.5
5	Critical	1	45.0	1	10.0
6	Maximum (Untreatable)	2	77.5	3	7.3
	Grand Average		53.0		14.2

AIS $\geq$ 2, and AIS $\geq$ 3) are plotted against impact speed, as shown in Figure 16. Logarithmic curves are fitted to the data with marginal goodness-of-fit as indicated by the coefficients of determination (R^2) ranging from 0.57 to 0.67. These fitted curves are intended for illustration purposes and may not necessarily be the best theoretical distribution that can be fitted to the data. Nevertheless, the trend of higher injury rates with increasing impact speed is clearly evident from the curves.

Figure 17 shows graphically the relationships between impact angles and injury rates. There are no apparent correlations between the injury rates and impact angle. Actually, linear regression lines fitted to the data even suggest that injury rates of AIS $\geq$ 2 and AIS $\geq$ 3 may decrease with greater impact angles although the results are insignificant statistically. This may partially be attributed to the general trend of higher impact speeds associated with smaller impact angles.

The lack of correlation between injury rates and velocity change is also evident from the graphs in Figure 18. This suggests that velocity change may not be a measure of accident severity for barrier impacts. This finding is not surprising considering the nature of a barrier impact in which the vehicle typically remains in contact with the barrier over a long period of time (as compared to impact with a point object such as a pole). Consequently, the velocity change is less abrupt and spread over a long period of time.

The type of barrier struck in the first barrier impact seems to have some effect on the injury severity, as illustrated in Table A.79. Bridge rail is associated with the highest percentage of AIS $\geq$ 3 (23.4%), followed by guardrail and median barrier. The lateral offset of the barrier has no significant effect on injury severity, as shown in Table A.80. On the other hand, impacts with bridge rail ends (50.0% AIS $\geq$ 3) and guardrail ends (35.7% AIS $\geq$ 3) result in much higher injury severity than impacts with normal sections of barriers (9.5% AIS $\geq$ 3), as shown in Table A.81. The sample size for impacts with guardrail to bridge rail transition is too small for meaningful evaluation. Also, barrier performance for the first barrier impact has some marginal effect on injury severity, as illustrated in Table A.82. Accidents in which the vehicle was redirected by the barrier have lower injury severity (12.2% AIS $\geq$ 3) than those in which the vehicle overrode, vaulted, or penetrated the barrier (20.0%-

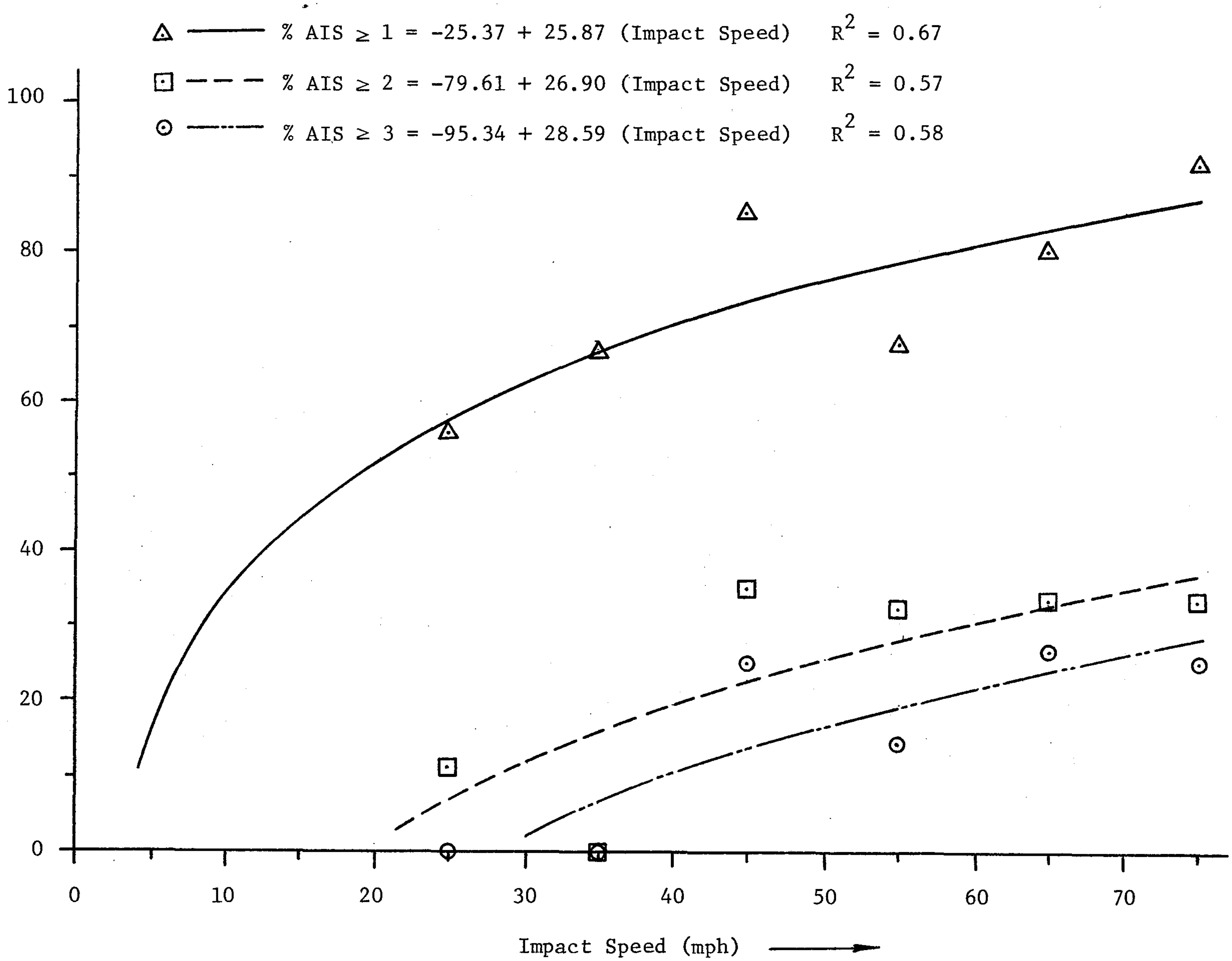


FIGURE 16. RELATIONSHIP BETWEEN INJURY RATE AND IMPACT SPEED OF FIRST BARRIER IMPACT

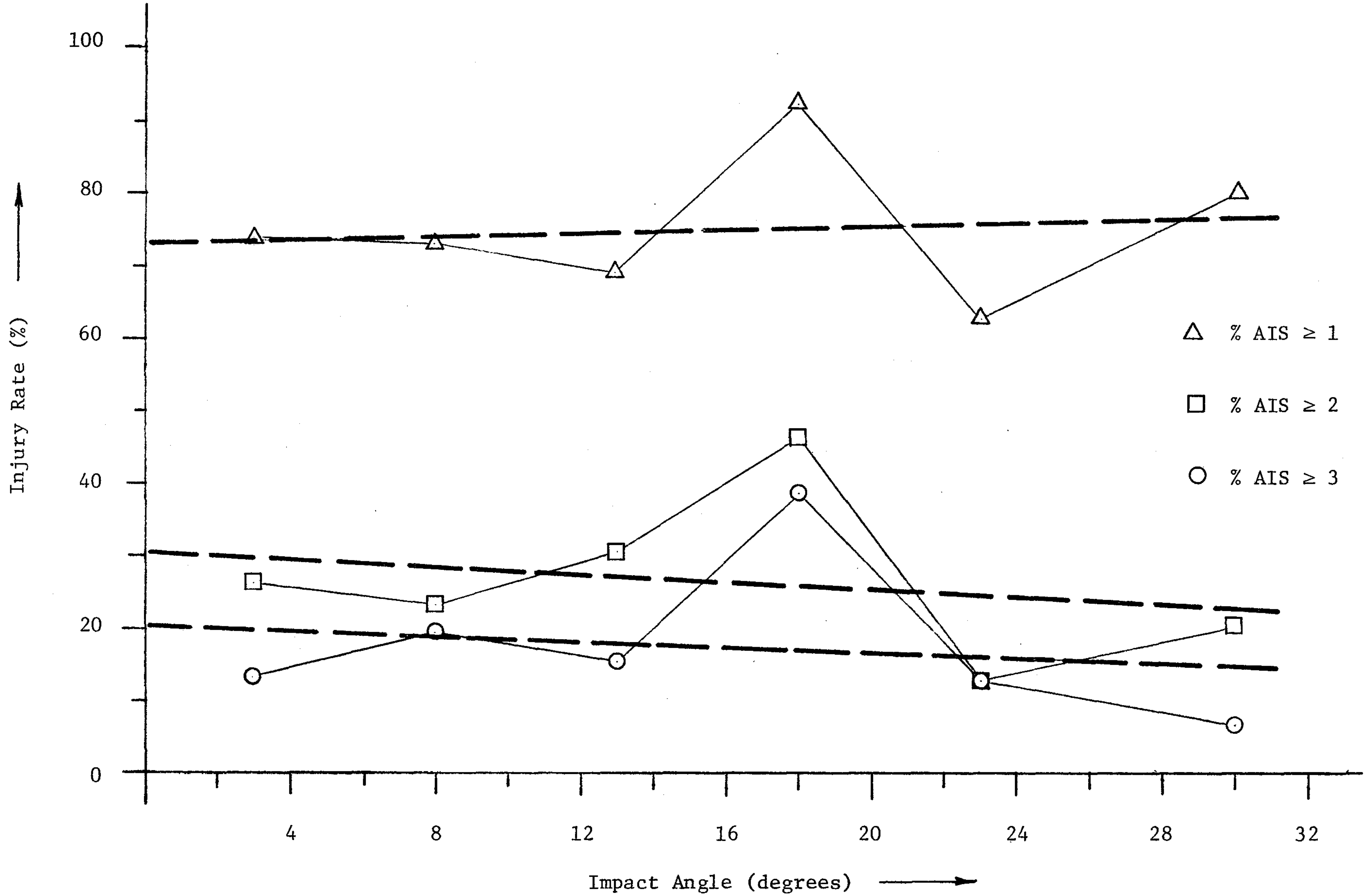


FIGURE 17. RELATIONSHIP BETWEEN INJURY RATE AND IMPACT ANGLE OF FIRST BARRIER IMPACT

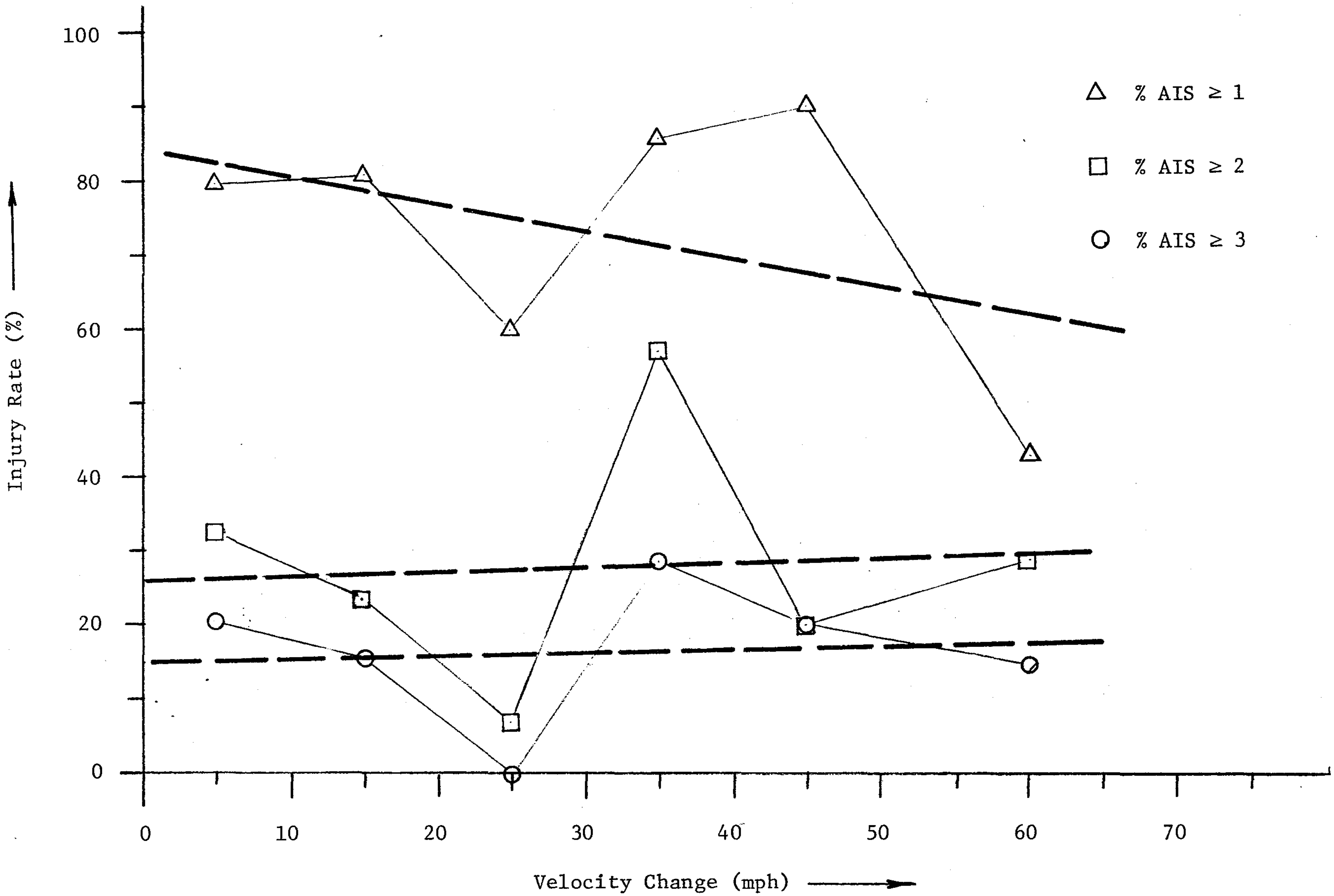


FIGURE 18. RELATIONSHIP BETWEEN INJURY RATE AND VELOCITY CHANGE OF FIRST BARRIER IMPACT

27.3% AIS $\geq$ 3).

Tables A.83 and A.84 display the distribution of injury severity by direction of force and vehicle deformation location, respectively. Twelve o'clock direction of impact has the highest percentge of AIS $\geq$ 3 (21.4%), but the differences are not statistically significant. Impacts involving the right side of the vehicle have the highest percentage of AIS $\geq$ 3 (37.5%) for some unknown reason, followed by frontal impacts (16.9% AIS $\geq$ 3). The results are marginally significant, but there is no apparent explanation for the high injury severity associated with right side impacts.

4.5.3 Most Severe Impact

The generally marginal relationships between injury severity and characteristics of the first barrier impact can be attributed to the fact that the first barrier impact accounts for only 58.7 percent of the most severe impacts, as shown in Table 30.

Impacts with barriers account for 80.0 percent of the most severe impact, as shown in Table 31. The remaining 20.0 percent involve other objects or impact types, such as rollovers and nonhorizontal impacts, and has the highest injury severity rate (47.8% AIS $\geq$ 3). For impacts involving barriers, bridge rail/guardrail end impacts are the most severe (41.7% AIS $\geq$ 3), followed distantly by bridge rail impact (13.9% AIS $\geq$ 3). The percentages of AIS $\geq$ 3 for guardrail or median barriers are negligible. The chi-square test result is highly significant on account of the high injury severity associated with bridge rail/guardrail end impacts and other non-barrier impacts. When the injury severities of bridge rail, guardrail and median barrier impacts are assessed separately, it appears that bridge rail impacts are more severe than impacts with guardrails or median barriers, but the results are only marginally significant. This difference in injury severity may be partially explained by the fact that bridge rails are generally designed to be more rigid with minimal deflection upon impact than guardrails and median barriers with the exception of the concrete safety shape.

The effects of impact speed and velocity change of the most severe impact on injury severity are shown in Tables 32 and 33. The trend of higher injury severity associated with greater impact speed, as is the case with the first barrier impact, is not present with the most severe impact. Actually, the highest percentage of AIS $\geq$ 3 is with the impact

TABLE 30

DISTRIBUTION OF MOST SEVERE IMPACT

Impact Number - Most Severe Impact	Frequency	Percent
1	71	58.7
2	34	28.1
3	11	9.1
4	4	3.3
5	1	0.8
Unknown	3	--
Total	124	100.0

TABLE 31

HIGHEST OCCUPANT INJURY SEVERITY BY OBJECT STRUCK - MOST SEVERE IMPACT

Object Struck - Most Severe Impact	Highest Injury Severity (AIS) 0		1		2		≥ 3		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Bridge Rail	12	33.3	14	38.9	5	13.9	5	13.9	36	31.3
Bridge Rail/ Guardrail End	3	25.0	3	25.0	1	8.3	5	41.7	12	10.4
Guardrail	6	42.9	8	57.1	0	0.0	0	0.0	14	12.2
Median Barrier	8	26.7	19	63.3	2	6.7	1	3.3	30	26.1
Other Object/ Impact Type	0	0.0	9	39.1	3	13.0	11	47.8	23	20.0
Total	29	25.2	53	46.1	11	9.6	22	19.1	115	100.0

$\chi^2 = 24.97$ d.f. = 4 (significant @ 0.0001)

Note. Another chi-square test is set up as follows:

	AIS ≤ 2	AIS ≥ 3
Bridge Rail	31	5
Guardrail	14	0
Median Barrier	29	1

$\chi^2 = 4.00$ d.f. = 2
(significant @ 0.135)

TABLE 32

HIGHEST OCCUPANT INJURY SEVERITY BY IMPACT SPEED
- MOST SEVERE IMPACT

Impact Speed (mph) - Most Severe Impact	Highest Injury Severity (AIS) 0		1		2		≥ 3		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
≤ 30	5	27.8	7	38.9	2	11.1	4	22.2	18	18.2
31-40	5	21.7	16	69.6	2	8.7	0	0.0	23	23.2
41-50	3	15.8	9	47.4	2	10.5	5	26.3	19	19.2
51-60	9	40.9	8	36.4	3	13.6	2	9.1	22	22.2
> 60	3	17.6	10	58.8	1	5.9	3	17.6	17	17.2
Total	25	25.3	50	50.5	10	10.1	14	14.1	99	100.0

$\chi^2 = 7.71$ d.f. = 4 (significant @ 0.103)

TABLE 33

HIGHEST OCCUPANT INJURY SEVERITY BY VELOCITY CHANGE
- MOST SEVERE IMPACT

Velocity Change (mph) - Most Severe Impact	Highest Injury Severity (AIS) 0		1		2		≥ 3		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
1-10	6	50.0	5	41.7	0	0.0	1	8.3	12	12.1
11-20	6	21.4	15	53.6	3	10.7	4	14.3	28	28.3
21-30	7	31.8	11	50.0	1	4.5	3	13.6	22	22.2
31-40	1	7.7	6	46.2	4	30.8	2	15.4	13	13.1
41-50	1	9.1	8	72.7	0	0.0	2	18.2	11	11.1
> 50	4	30.8	5	38.5	2	15.4	2	15.4	13	13.1
Total	25	25.3	50	50.5	10	10.1	14	14.1	99	100.0

$\chi^2 = 0.52$ d.f. = 5 (Not significant) speed range of 41-50 mph (26.3%), followed by the speed range of 30 mph or less (22.2%). The marginally significantly chi-square test result simply reflects the differences between the various speed ranges. As for velocity change, there is a weak trend of higher injury severity associated with greater velocity change, but the result is not statistically significant. It seems that the type of object struck overshadows the effects of impact speed or velocity change for the most severe impact.

As shown earlier in Tables A.52 through A.55, the distributions of vehicle damage characteristics of the most severe impact are different from those of the barrier impacts. Rollovers and other nonhorizontal impacts (i.e., direction of force = 00; vehicle deformation location = top or undercarriage; vehicle damage distribution = rollover) are greatly overrepresented as the most severe impact in relation to their occurrences. On the other hand, impacts on the sides and back of vehicles with 3-9 o'clock direction of force and of a sideswipe or corner impact nature are underrepresented.

The vehicle damage extent for the most severe impact is expectedly higher than that of barrier impacts. For instance, 34.7 percent having damage extent codes of 3-6 compared to only 14.0 percent for barrier impacts. On the other hand, damage extent codes of 8 and 9, which are generally associated with sideswipe type of impact, account for only 8.9 percent of the most severe impact as compared to 17.8 percent for barrier impacts.

Tables 34 and 35 illustrate the distributions of injury severity by vehicle deformation location and direction of force for the most severe impact. As discussed earlier, rollovers and other nonhorizontal impacts have much higher injury severity than barrier impacts and the data from these two tables simply reaffirms this finding. When only horizontal impacts are considered, all severe impacts with AIS $\geq$ 3 are frontal impacts, most of which have a 12 o'clock direction of force. The severity of impacts on the back and sides of vehicles or with 2-10 o'clock direction of force is negligible.

4.6 Summary and Discussion

The development of the ACCIDENT file and descriptive statistics concerning the file have been discussed in this chapter. The ACCIDENT file contains in-depth data on 124 single vehicle bridge accidents in which there was one or more fatalities or the first impact was with a bridge

TABLE 34

HIGHEST OCCUPANT INJURY SEVERITY BY VEHICLE DEFORMATION LOCATION - MOST SEVERE IMPACT

Vehicle Deformation Location - Most Severe Impact	Highest Injury Severity (AIS)								Total	
	0		1		2		≥ 3			
	No.	%	No.	%	No.	%	No.	%	No.	%
Front	21	26.6	34	43.0	9	11.4	15	19.0	79	71.2
Right Side	0	0.0	3	100.0	0	0.0	0	0.0	3	2.7
Left Side	2	28.6	5	71.4	0	0.0	0	0.0	7	6.3
Back	2	40.0	3	60.0	0	0.0	0	0.0	5	4.5
Top	0	0.0	6	50.0	2	16.7	4	33.3	12	10.8
Undercarriage	2	40.0	1	20.0	0	0.0	2	40.0	5	4.5
Total	27	24.3	52	46.8	11	9.9	21	18.9	111	100.0

Note. Two separate χ^2 tests are set up as follows:

1.

	AIS ≤ 2	AIS ≥ 3	
Front, Back & Sides	79	15	$\chi^2 = 3.51$ d.f. = 1
Top & Undercarriage	11	6	(significant @ 0.061)

2.

	AIS ≤ 2	AIS ≥ 3	
Front	64	15	$\chi^2 = 3.39$ d.f. = 1
Back & Sides	15	0	(significant @ 0.066)

TABLE 35

HIGHEST OCCUPANT INJURY SEVERITY BY DIRECTION OF FORCE - MOST SEVERE IMPACT

Direction of Force - Most Severe Impact	Highest Injury Severity (AIS) 0		1		2		≥ 3		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
12 o'clock	12	26.7	19	42.2	5	11.1	9	20.0	45	40.5
1 & 11	6	27.3	12	54.5	2	9.1	2	9.1	22	19.8
2 & 10	4	33.3	7	58.3	0	0.0	1	8.3	12	10.8
3-9 o'clock	3	27.3	6	54.5	2	18.2	0	0.0	11	9.9
Nonhorizontal Force	2	9.5	8	38.1	2	9.5	9	42.9	21	18.9
Total	27	24.3	52	46.8	11	9.9	21	18.9	111	100.0

Note. Two separate χ^2 tests are set up as follows:

1.

	AIS ≤ 2	AIS ≥ 3	
Horizontal Force	78	12	$\chi^2 = 9.68$ d.f. = 1
Nonhorizontal Force	12	9	(significant @ 0.002)

2.

	AIS ≤ 2	AIS ≥ 3	
12 o'clock	36	9	$\chi^2 = 4.03$ d.f. = 3
1 & 11	20	2	(Not significant)
2 & 10	11	1	
3-9 o'clock	11	0	

rail, bridge end, or approach guardrail. Highlights of notable findings are as follows.

- The highest accident occurrence is on weekends and during late night and early morning hours. Adverse driving conditions, such as wet pavement, do not appear to have any significant effect on accident occurrence.

- Over three-quarters of the accidents occur in urban areas and on roadways with access control, i.e., interstate highways and expressways. The accident bridges generally have very gentle horizontal and vertical alignments. Over half of the bridges have ADT in excess of 35,000 and between 6 to 10 percent of trucks in the traffic mix.

- The accident vehicles are fairly distributed between mini/subcompact, compact, intermediate and full size vehicles with 71.8 percent of the vehicle curb weights between 3,000 to 4,000 pounds and another 20.1 percent less than 3,000 pounds. Surprisingly, there are no significant differences in resultant injury severity between the various vehicle sizes and weight ranges.

- The majority (70.2%) of the vehicles have the driver as the only occupant. The drivers are mostly male (70.8%) and 25 years of age or younger (50.8%). The restraint usage rate is a low 11 percent for drivers. Over 70 percent of the drivers are injured (AIS $\geq$ 1), 14.2 percent of which are severe to fatal injuries (AIS $\geq$ 3).

- As for the occupants receiving the highest injury severity, 83.1 percent are drivers, 12.9 percent are front seat passengers and the remaining 4 percent are rear seat passengers. The restraint usage rate is only 8.4 percent. The highest occupant injury is expectedly more severe than driver injury with 18.4 percent receiving AIS $\geq$ 3.

- The majority (61.6%) of the departure angles are 15 degrees or less with an average of 14.6 degrees and an average departure speed of 52.9 miles per hour. Over three-quarters of the vehicles are tracking or yawing at 30 degrees or less. The distance travelled from departure to first impact is usually very short with only 22.6 percent of the vehicles travelling more than 50 feet.

- Over three-quarters (77.4%) of the accidents involve more than one impact, half of which are three or more impacts. The injury severity of the accident increases with the total number of impacts from 14.3 percent

AIS $\geq$ 2 for single impact accidents to 40.0 percent AIS $\geq$ 2 for accidents with four or more impacts. This clearly indicates the importance of subsequent impacts for accidents involving barriers.

- Over half (52.4%) of the first impacts occur in Approach 1 with 32.3 percent on the bridge itself and only 11.3 percent in Approach 2. The majority (56.5%) of the first impacts involve guardrails or median barriers with guardrail end or transition sections accounting for 12.9 percent. Bridge rail accounts for 25.8 percent of the first impacts with bridge rail/parapet end another 6.5 percent.

- For the first barrier impact, the average impact angle is 14.4 degrees and 87.1 percent of the impact angles are at 25 degrees or less. The average impact speed is 50.6 miles per hour with 73.1 percent of the impact speeds at 60 miles per hour or less. It appears that the impact conditions currently used in full-scale crash testing of longitudinal barriers, i.e., impact speed of 60 miles per hour and impact angles of 15 and 25 degrees, are good approximations of the average and limiting impact conditions. There is a weak trend indicating that higher impact speeds are associated with smaller impact angles. Also, 74 percent of the vehicles are either tracking or yawing at 30 degrees or less at impact.

- Velocity changes for the first barrier impacts are fairly low in relation to the impact speeds, indicating that the impacting vehicles retain a large proportion of their impact speeds after separating from the barriers and subsequent impacts are also of considerable importance.

- The front of the vehicle accounts for 74.8 percent of the first barrier impacts and 76.6 percent sustained 11, 12 or one o'clock direction of force with 12 o'clock alone accounting for 54.1 percent. The vehicle damage extent is mostly very minor with 71.2 percent having extent codes of one or two and another 16.1 percent of the sideswipe nature.

- Damages to the barriers are mostly very minor with length of deformation 50 feet or shorter and depth of deformation 18 inches or less.

- The impacting vehicle is redirected or comes to rest against the barrier in 73.1 percent of the first barrier impacts and the separation angle is usually very gentle. However, 22.7 percent of the impacts resulted in improper performance by the barrier, including overriding (10.1%), vaulting (8.4%) and penetration (4.2%).

- For the first barrier impact, higher injury severity is associated with increasing impact speed, but not with impact angle or velocity change.

Also, injury severity is lower if the vehicle is redirected than if the vehicle overrode, vaulted or penetrated the barrier.

- For subsequent barrier impacts, the impact speeds are lower, but the impact angles are higher than the first barrier impacts. Also, the vehicles are more likely to be yawing and impacts with the sides or back of the vehicles are more frequent with directions of force between two and ten o'clock. This indicates that the vehicle trajectories for subsequent impacts are more abrupt although the impact speeds are lower.

- The first barrier impacts account for only 58.7 percent of the most severe impacts with subsequent barrier impacts another 21.3 percent, and the remaining 20 percent involve other objects or impact types.

- Rollovers and nonhorizontal impacts have the highest injury severity rate (47.8% AIS $\geq$ 3), followed by impacts with bridge rail/guardrail ends (41.7% AIS $\geq$ 3). As for barrier impacts, bridge rail impacts are slightly more severe than those with guardrails or median barriers.

- For the most severe impacts, higher injury severity is not associated with impact speed and only marginally with greater velocity change, indicating the predominance of the effects of impact type on injury severity.

CHAPTER V. SAMPLE FILE

5.1 Introduction

Data from the POPULATION file, discussed in Chapters II and III, was adequate to define the extent of the narrow bridge accident problem. However, the file lacks sufficient details for more in-depth analysis, such as identifying significant accident contributory factors and countermeasure effectiveness. Thus, a second data base, called the SAMPLE file, was created by selecting a small sample of the POPULATION bridges for extensive manual field data collection to supplement the existing data in the POPULATION file.

Budgetary considerations limited the total number of sampled bridges to about 2,000 out of the total of 11,880 bridges. Most of the POPULATION bridges were either two-lane undivided single structures or two-lane twin structures. Thus, a decision was made to include only these two structure types in the sample. To assure proper representation, it was decided that the sampling scheme should control for at least the narrowness categories and ADT groups. Finally, accident level was added as a third controlling factor.

This chapter discusses the creation of the SAMPLE file and presents some descriptive statistics of its contents.

5.2 Creation of SAMPLE File

5.2.1 Sampling Scheme

A disproportional stratified random sampling scheme was eventually chosen for selecting the sample bridges. The stratification criteria included:

1. Narrowness categories defined by:
   a. Bridge curb-to-curb width
   b. Shoulder reduction
2. ADT groups
3. Accident level ("0" versus "> 0" in accident rate).

Table 36 illustrates the setup of the stratification scheme and the distribution of bridges. There are a total of 60 cells, consisting of:

1. Two-lane undivided bridges

   7 (narrowness categories) x 3 (ADT groups) x 2 (accident levels) = 42 cells

2. Two-lane twin structures

3 (narrowness categories) x 3 (ADT groups) x 2 (accident levels) = 18 cells

The desired sample size for each cell was 40 bridges for a total of 60 cells x 40 bridges/cell = 2,400 bridges. However, the distribution of the bridges is very uneven, as shown in Table 36, with many of the cells having less than 40 bridges. This necessitated modifications to sample sizes of the individual cells.

For two-lane undivided bridges, 80 percent had no accidents, yet some of the cells in the $\geq$ 3,000 ADT group have fewer than 40 bridges. On the other hand, for bridges with accidents, very few are in the 1-399 ADT group or in the non-narrow category for bridges less than 24 feet in curb-to-curb width. It was then decided that bridges in cells with fewer than 40 bridges would be sampled 100 percent. The difference would be made up by increasing the sample size in other ADT groups so that 120 bridges would be sampled for each combination of narrowness category and accident level. Even this was unattainable for some narrowness categories with accident level > 0. Eventually, a total of 1,463 two-lane undivided bridges was sampled, 217 fewer than if 40 bridges had been sampled from each of the 42 cells.

For two-lane twin structures, only 30 percent of the bridges had no accidents with very few in the ADT group of $\geq$ 20,000. Since bridges with no accidents are intended for comparison purposes only (the accident rate and severity are always zero), the sample size per cell can be reduced with little or no adverse effect. The sample size per cell was thus reduced to 20 for bridges with no accidents while the sample size was increased to 60 per cell for bridges with accidents. Again, the uneven distribution of bridges necessitated further revisions to the sample size of individual cells. Table 37 illustrates the eventual sample sizes used for the various cells with a total of 636 two-lane twin structures sampled (84 fewer than the desired number of 720 bridges).

5.2.2 Field Data Collection

In accordance with the sampling scheme of Table 37, 2,099 bridges were randomly selected from the POPULATION file to generate the SAMPLE file. Final bridge counts by State were as follows:

Arizona	130
Michigan	254

TABLE 36

DISTRIBUTION OF BRIDGES BY STRATIFICATION SCHEME

Two-Lane Undivided Bridges

Narrowness Category (Accident Level / ADT Group)		0				> 0				TOTAL
		1-399	400 - 2,999	≥ 3,000	Subtotal	1-399	400 - 2,999	≥ 3,000	Subtotal	
≤ 20.0'	Bridge < Approach	344	161	5	510	2	59	11	72	582
	Bridge ≥ Approach	199	44	0	243	1	4	3	8	251
20.1'-24.0'	Bridge < Approach	656	557	17	1230	2	131	120	253	1483
	Bridge ≥ Approach	459	234	2	695	3	40	20	63	758
> 24.0'	> 50% Shoulder Reduction	66	309	77	452	0	102	242	344	796
	1-50% Shoulder Reduction	179	407	70	656	2	110	123	235	891
	No Shoulder Reduction	399	939	192	1530	2	132	218	352	1882
TOTAL		2302	2651	363	5316	12	578	737	1327	6643

Two-Lane Twin Structures

Narrowness Category (Accident Level / ADT Group)	0				> 0				TOTAL
	1-4,999	5,000 - 19,999	≥ 20,000	Subtotal	1-4,999	5,000 - 19,999	≥ 20,000	Subtotal	
≤ 24.0', or > 24.0', > 50% Shoulder Reduction	20	15	0	35	36	144	55	235	270
> 24.0', 1-50% Shoulder Reduction	23	19	0	42	13	74	27	114	156
> 24.0' No Shoulder Reduction	136	84	6	226	71	248	48	367	593
TOTAL	179	118	6	303	120	466	130	716	1019

TABLE 37

PLANNED SAMPLE SIZE BY STRATIFICATION SCHEME

Two-Lane Undivided Bridges

Narrowness Category		0				> 0				TOTAL
Accident Level / ADT Group		1-399	400 - 2,999	≥ 3,000	Subtotal	1-399	400 - 2,999	≥ 3,000	Subtotal	
≤ 20.0'	Bridge < Approach	57	58	5	120	2	59	11	72	192
	Bridge ≥ Approach	76	44	0	120	1	4	3	8	128
20.1'-24.0'	Bridge < Approach	51	52	17	120	2	59	59	120	240
	Bridge ≥ Approach	59	59	2	120	3	40	20	63	183
> 24.0'	> 50% Shoulder Reduction	40	40	40	120	0	60	60	120	240
	1-50% Shoulder Reduction	40	40	40	120	2	59	59	120	240
	No Shoulder Reduction	40	40	40	120	2	59	59	120	240
TOTAL		363	333	144	840	12	340	271	623	1463

Two-Lane Twin Structures

Narrowness Category	0				> 0				TOTAL
Accident Level / ADT Group	1-4,999	5,000 - 19,999	≥ 20,000	Subtotal	1-4,999	5,000 - 19,999	≥ 20,000	Subtotal	
≤ 24.0', or > 24.0', > 50% Shoulder Reduction	20	15	0	35	36	114	55	205	240
> 24.0', 1-50% Shoulder Reduction	23	19	0	42	13	74	27	114	156
> 24.0' No Shoulder Reduction	27	27	6	60	66	66	48	180	240
TOTAL	70	61	6	137	115	254	130	499	636

Montana	237
Texas	1158
Washington	320
Total	2099

Appropriate forms and instructions were developed for the field data collection effort and field data were collected during the summer and fall months of 1980. In the interest of expediting data collection and minimizing measurement errors, a simple check-type of field form was used rather than coded forms or forms requiring category determinations. This selection complicated subsequent office work in that the data had to be coded for keypunch from the field forms and more programming effort and consistency checks were required in generating the final SAMPLE file.

To the extent possible, photologs and documentation in the State highway offices were used as sources for the required data. Specific sources and procedures used for each of the study States follow.

Arizona. Photologs in the State office at Phoenix were used for most of the data elements. A supplemental, computerized bridge file and as-built plans were obtained for determination of vertical and horizontal alignment data at the bridges.

Michigan. Photologs in the State office at Lansing were used. Copies of as-built plans were obtained to determine vertical and horizontal alignment data.

Montana. Photologs in the State office at Helena were used to the extent possible. Strip charts were used for extracting vertical and horizontal alignment data. However, difficulties were encountered with finding data sources for 78 bridges and actual site visits were made to these bridges to collect the necessary field data and measurements.

Texas. Texas had neither photologs nor readily available information concerning the bridges, particularly safety treatment information. Thus, actual bridge site visits were deemed necessary. Detailed, large-scale highway maps were obtained and the bridges were located and marked on these maps. These bridge sites were then visited and the necessary field data and measurements were collected.

Washington. Photologs in the State office at Olympia were used for most of the data elements. Copies of computerized vertical alignment and horizontal alignment files were furnished by the State, from which the necessary alignment data was easily extracted.

Of the original 2,099 bridges, 1,989 were eventually included in the final SAMPLE file. The other 110 bridges were eliminated for various reasons as follows:

1. The bridge could not be located due to erroneous location identification data.
2. The bridge was reconstructed or demolished.
3. The bridge did not meet the study criteria, e.g., eliminated from State system, culvert, interchange, etc.
4. The number of lanes on the bridge was different from that of the approaches due to the presence of entrance or exit ramp, passing lane, lane drop, etc.

Table 38 shows the final sample size for each of the stratification cells with the weighting factor shown in parentheses. The weighting factor is the inverse of the sampling rate for bridges in that particular cell. For example, if a cell has 200 bridges, 40 of which are sampled, the sampling rate is 40/200 = 0.2 and the weighting factor is 1/0.2 = 5. For purposes of analysis, each bridge is weighted by its corresponding weighting factor. In this example, a bridge from that cell is considered as 5 bridges (weighting factor of 5) for analysis purposes. The use of weighting factors does complicate the analyses, but was considered necessary to assure proper statistical analyses.

5.2.3 Data Processing

As indicated in the previous section, a simple check-type of field form was used to expedite field data collection and minimize measurement errors. However, this simplistic approach complicated subsequent programming effort primarily in that combinations of descriptive data items had to be considered in establishing the final configuration. For example, curbs were checked as right, left, or neither, then as mountable or non-mountable, and finally with the height. The programming logic involved in coding all possible combinations even with this simple example is obvious.

The collected data was then coded directly from the field forms, checked independently, and submitted for keypunch and verification. One-way tables of the raw data were then prepared for preliminary checks on the validation and consistency of the file. The errors were manually checked and corrected, and the corrections were keypunched for updating of the file. This process was repeated until the file was determined to be substantially correct.

TABLE 38

FINAL SAMPLE SIZES AND WEIGHTING FACTORS

Two-Lane Undivided Bridges

Narrowness Category	ADT Group	Accident Level 0: 1-399	0: 400 - 2,999	0: ≥ 3,000	0: Subtotal	> 0: 1-399	> 0: 400 - 2,999	> 0: ≥ 3,000	> 0: Subtotal	TOTAL
≤ 20.0'	Bridge < Approach	55 (6.255)	52 (3.096)	3 (1.667)	110 (4.636)	2 (1.000)	52 (1.135)	11 (1.000)	65 (1.108)	175 (3.326)
	Bridge ≥ Approach	72 (2.764)	43 (1.023)	0 (1.000)	115 (2.113)	1 (1.000)	3 (1.333)	3 (1.000)	7 (1.143)	122 (2.057)
20.1'- 24.0'	Bridge < Approach	49 (13.388)	51 (10.922)	15 (1.133)	115 (10.696)	2 (1.000)	56 (2.339)	57 (2.105)	115 (2.200)	230 (6.448)
	Bridge ≥ Approach	59 (7.780)	59 (3.966)	1 (2.000)	119 (5.840)	3 (1.000)	37 (1.081)	17 (1.176)	57 (1.105)	176 (4.307)
> 24.0'	> 50% Shoulder Reduction	40 (1.650)	40 (7.725)	36 (2.139)	116 (3.897)	0 (1.000)	56 (1.821)	58 (4.172)	114 (3.018)	230 (3.461)
	1-50% Shoulder Reduction	40 (4.475)	41 (9.927)	39 (1.795)	120 (5.467)	2 (1.000)	57 (1.930)	53 (2.321)	112 (2.098)	232 (3.841)
	No Shoulder Reduction	39 (10.231)	40 (23.475)	38 (5.053)	117 (13.077)	2 (1.000)	57 (2.316)	55 (3.964)	114 (3.088)	231 (8.147)
TOTAL		354 (6.503)	326 (8.132)	132 (2.750)	812 (6.547)	12 (1.000)	318 (1.818)	254 (2.902)	584 (2.272)	1396 (4.759)

Two-Lane Twin Structures

Narrowness Category / ADT Group	Accident Level 0: 1-4,999	0: 5,000 - 19,999	0: ≥ 20,000	0: Subtotal	> 0: 1-4,999	> 0: 5,000 - 19,999	> 0: ≥ 20,000	> 0: Subtotal	TOTAL
≤ 24.0', or > 24.0', > 50% Shoulder Reduction	19 (1.053)	14 (1.071)	0 (1.000)	33 (1.061)	35 (1.029)	110 (1.309)	46 (1.196)	191 (1.230)	224 (1.205)
> 24.0', 1-50% Shoulder Reduction	23 (1.000)	18 (1.056)	0 (1.000)	41 (1.024)	12 (1.083)	69 (1.072)	27 (1.000)	108 (1.056)	149 (1.047)
> 24.0' No Shoulder Reduction	25 (5.440)	24 (3.500)	5 (1.200)	54 (4.185)	63 (1.127)	60 (4.133)	43 (1.116)	166 (2.211)	220 (2.695)
TOTAL	67 (2.672)	56 (2.107)	5 (1.200)	128 (2.367)	110 (1.091)	239 (1.950)	116 (1.121)	465 (1.540)	593 (1.718)

On completion of the consistency checks, the field data was converted to the SAMPLE file by appropriate code transformations and processing. New variables of interest, such as summary data elements and narrowness stratifications, were created. The data elements in the final SAMPLE record are shown in Appendix A. This bridge data file was finally merged with accident data from the POPULATION file to create the records for analysis purposes.

5.3 Description of SAMPLE File

5.3.1 Weighted Versus Unweighted Data

As indicated in Section 5.2.2 above, sampled bridges were weighted for analysis purposes by their respective weighting factors. Thus, the 572 bridges on divided highways were increased in number to 1,088 and the 1,417 bridges on undivided highways to 6,574. Descriptive statistics that follow in the next sections pertain to the weighted data. In this section, the unweighted data is used to indicate how well the SAMPLE file data extrapolations are likely to represent the POPULATION file.

Tables 39 and 40 show comparisons of the bridge narrowness strata for the SAMPLE file and POPULATION file for the 572 sampled bridges on divided highways and the 1,417 sampled bridges on undivided highways, respectively. On inspecting these tables, it is not surprising that discrepancies exist on the shoulder reductions. As discussed in Chapter II, assumptions had to be made concerning shoulder widths in using the Bridge Inventory file to create the POPULATION file. Some inconsistencies between data collectors undoubtedly resulted even with the sampled bridges because of the difficulties in defining "stabilized" shoulders and in establishing the shoulder edges.

Of more serious consequence are the discrepancies in structure type. Note in Table 39 that 45 (7.9%) of the sampled two-lane twin structures were identified as single undivided structures in the POPULATION file. In Table 40, 66 (4.7%) of the sampled two-lane undivided structures were identified as twin structures. These inconsistencies could be caused by a number of factors, including definitional differences between the States in setting up the Bridge Inventory file, definitional discrepancies in converting the bridges to the POPULATION file, coding errors, etc. In any case, the SAMPLE file is not completely representative of the POPULATION bridges, and some error is to be expected in extrapolations of the sampled

TABLE 39

COMPARISON OF SAMPLE FILE AND POPULATION FILE BRIDGE TYPES FOR DIVIDED HIGHWAYS

				SAMPLE File Two-Lane Twin Structures							
				≤ 24'	> 24', > 50% Shoulder Reduction	> 24', 1-50% Shoulder Reduction	> 24', No Shoulder Reduction	> 24', No Approach Shoulder	Unknown	Total	
POPULATION File	Twin Structures	2-Lane	≤ 24'	10	1	5	0	0	0	16	
			> 24', > 50% Shoulder Reduction	1	164	12	4	2	1	184	
			> 24', 1-50% Shoulder Reduction	0	14	63	37	1	0	115	
			> 24', No Shoulder Reduction	0	3	64	145	0	0	212	
	Single Structure, Undivided	2-Lane	18-20' Bridge < Approach Width	1	0	0	0	0	0	1	45 (7.9%)
			20-22' Bridge ≥ Approach Width	0	0	0	1	0	0	1	
			22-24' Bridge < Approach Width	2	0	0	0	0	0	2	
			22-24' Bridge ≥ Approach Width	0	1	0	0	0	0	1	
			> 24', > 50% Shoulder Reduction	1	4	0	1	0	0	6	
			> 24', 1-50% Shoulder Reduction	0	2	6	6	0	0	14	
			> 24', No Shoulder Reduction	0	0	2	18	0	0	20	
			Total	15	189	152	212	3	1	572	

TABLE 40

COMPARISON OF SAMPLE FILE AND POPULATION FILE BRIDGE TYPES FOR UNDIVIDED HIGHWAYS

SAMPLE FILE

Two-Lane Undivided Structures

POPULATION File			≤ 20' S.R.	≤ 20' No S.R.	≤ 20' No App. Sh.	20-22' S.R.	20-22' No S.R.	20-22' No App. Sh.	22-24' S.R.	22-24' No S.R.	22-24' No App. Sh.	> 24' > 50% S.R.	> 24' 1-50% S.R.	> 24' No S.R.	> 24' No App. Sh.	Unknown	Total
Single Structure, Undivided		≤ 18' Br. < App.	7	0	1	1	0	0	1	0	0	1	2	3	0	0	16
		≤ 18' Br. ≥ App.	2	0	1	0	0	0	0	0	0	0	0	0	1	0	4
		18-20' Br. < App.	82	9	52	2	1	1	2	0	0	1	2	4	2	0	158
		18-20' Br. ≥ App.	58	7	28	2	2	3	2	1	3	4	3	2	3	0	118
		20-22' Br. < App.	1	0	1	19	0	7	1	0	3	0	0	3	1	0	36
		20-22' Br. ≥ App.	6	0	0	14	2	5	0	0	1	0	2	2	0	0	32
		22-24' Br. < App.	0	0	2	9	2	3	116	17	28	5	2	6	2	0	192
		22-24' Br. ≥ App.	1	0	1	10	0	3	54	31	33	3	4	1	0	1	142
		> 24' > 50% S.R.	0	0	0	0	0	0	11	3	6	163	22	11	8	0	224
		> 24' 1-50% S.R.	0	0	0	0	0	0	6	0	1	46	111	40	14	0	218
		> 24' No S.R.	0	0	0	1	0	0	3	4	3	25	32	129	14	0	211
Twin Structures	2-Lane	≤ 24'	0	0	0	0	0	0	0	0	0	2	1	0	0	0	3
		> 24' > 50% S.R.	0	0	0	0	0	0	0	0	0	18	3	0	0	0	21
		> 24' 1-50% S.R.	0	0	0	0	0	0	0	0	0	0	1	33	0	0	34
		> 24' No S.R.	0	0	0	0	0	0	0	0	0	0	0	8	0	0	8
		Total	157	16	86	58	7	22	196	56	78	268	185	242	45	1	1417

66 (4.7%)

bridge data. It is considered that the error is not significant - probably less than 10 percent.

5.3.2 General Bridge Characteristics

This section describes some of the general bridge characteristics for the weighted sampled bridges. Only salient features are noted here. Tables showing more complete descriptive statistics are included in Appendix J. Also, for the sake of simplicity, two-lane undivided single structures are referred to as undivided bridges or roadways and two-lane twin structures as divided bridges or roadways.

Table A.85 shows the distributions of bridge roadway width by bridge length for undivided and divided roadways. As expected, the undivided highway bridges are narrow with 47.4 percent 24 feet or less in width and only 16.5 percent greater than 36 feet. In comparison, most of the divided highway bridges are wide with only 1.8 percent having widths of 24 feet or less and 66 percent greater than 36 feet. The majority of the bridges are less than 200 feet in length (61.4% for divided and 76.0% for undivided). Also, the bridge width is inversely proportional to the bridge length, i.e., the longer the bridge, the narrower the bridge. Take bridges on divided roadways as an example. The percentage of bridges with lengths greater than 200 feet decreases from 55 percent for bridges 24 feet or less in width to 22.8 percent for bridges with widths greater than 40 feet. The corresponding percentages for bridges on undivided roadways are 84 percent ($\leq$ 24 feet) and 25.8 percent (> 40 feet). This reflects the high costs associated with the bridge structures and the trend to keep the bridge as narrow as possible, especially for long structures.

Similar observations as above may be drawn from Table A.86 which illustrates the distribution of percent shoulder reduction by bridge length. As the bridge length increases, the percentage of bridges with shoulder reduction increases and the extent of shoulder reduction also increases as reflected by the increasing proportion of bridges with greater percentage of shoulder reduction. Take undivided bridges as an example. Bridges less than 200 feet in length have 29.3 percent with no shoulder reduction, 21.4 percent with 1 to 60 percent shoulder reduction, and 26.8 percent with 61 to 100 percent shoulder reduction. The corresponding percentages for bridges larger than 200 feet are: 24.6 percent, 13.4 percent, and 48.6 percent, respectively.

Table A.87 shows the distribution of percent shoulder reduction by bridge roadway width. For undivided bridges with widths of 24 feet or less, about one-third (32.9%) have no approach shoulders and 38.8 percent have over 60 percent shoulder reduction. Then, as the bridge width increases, the percentage of bridges with no approach shoulder decreases while that with no shoulder reduction increases. As for divided bridges, the percentage of bridges with no shoulder reduction increases drastically above bridge widths of 36 feet (77.7%) while only two of the 160 bridges with shoulder reduction are above 40 percent shoulder reduction. In comparison, for divided bridges with widths of 36 feet or less, only 6.8 percent have no shoulder reduction while 95.9 percent of the bridges with shoulder reduction are above 40 percent shoulder reduction.

The distributions of 1977 ADT by bridge roadway width are shown in Table A.88 for undivided and divided roadways. The majority of the undivided structures (60.5%) have ADT's of less than 1,000 vehicles per day while 51.4 percent of the divided structures have ADT's of more than 8,000 vehicles per day. Practically all (98.7%) of the divided bridges have ADT's of more than 1,000 vehicles per day.

Table A.89 shows the distribution of vertical alignment by horizontal alignment for the weighted bridges. As expected, most of the bridges are straight (93.9% for undivided and 83.2% for divided). Many of the undivided straight structures are also level (37.9%), typically indicating the older practice of making necessary grade changes on the approaches.

Average values for the various components of the bridge and its two approaches are summarized in Table 41. Approach 1 denotes the approach to the bridge in the direction of increasing milepoint for undivided bridges while, for divided bridges, Approach 1 is the approach to the bridge in the direction of vehicle travel.

For two-lane undivided bridges, the average approach roadway width is 29.8 feet with 11-foot lanes. Shoulders are present in over 77 percent of the bridge approaches with an average shoulder width of just over 5 feet. The average bridge roadway width is slightly narrower than the approach at 27.7 feet with shoulders present in 73.6 percent of the bridges and an average shoulder width of 3.7 feet. Curbs are rarely present in the approaches (2.6%) though over half of the bridges have curbs (52.4%) and the curb height is a high 9.4 inches. Curved horizontal alignment is

TABLE 41

AVERAGE APPROACH AND BRIDGE VALUES

Data Item	2-Lane Undivided Single Structure			2-Lane Divided Twin Structure		
		Weighted N			Weighted N	
	Average	No.	%	Average	No.	%
APPROACH 1 DATA						
Lane Width	11.0'	6574	100.0	12.0'	1087	99.9
Right Shoulder Width	5.1'	5084	77.3	9.6'	1084	99.6
Left Shoulder Width	5.1'	5071	77.1	5.7'	1067	98.1
Total Approach Width	29.8'	6574	100.0	39.2'	1087	99.9
Curb Height	6.1"	168	2.6	5.8"	147	13.5
Degree of Curvature	4.2°	2123	32.3	1.8°	318	29.2
Tangent Distance	163'	2136	32.5	102'	318	29.2
Sight Distance	724'	2123	32.3	843'	318	29.2
Right Guardrail - Length	149'	3436	52.3	284'	1061	97.5
Left Guardrail - Length	146'	3215	48.9	200'	1013	93.1
Median Barrier - Presence	--	--	--	--	27	2.5
BRIDGE DATA						
Bridge Length	169'	6571	100.0	245'	1088	100.0
Lane Width	11.2'	6574	100.0	12.0'	1088	100.0
Right Shoulder Width	3.7'	4840	73.6	7.7'	1076	98.9
Left Shoulder Width	3.6'	4841	73.6	5.2'	1071	98.4
Bridge Roadway Width	27.7'	6572	100.0	36.8'	1087	100.0
Curb Height	9.4"	3447	52.4	10.3"	713	65.5
Degree of Curvature	3.3°	399	6.1	1.7°	183	16.8
APPROACH 2 DATA						
Lane Width	10.9'	6573	100.0	12.0'	1087	99.9
Right Shoulder Width	5.2'	5117	77.8	9.8'	1083	99.5
Left Shoulder Width	5.0'	5116	77.8	5.7'	1062	97.6
Total Approach Width	29.8'	6573	100.0	39.3'	1087	99.9
Curb Height	6.1"	180	2.7	5.6"	153	14.1
Degree of Curvature	4.2°	2191	33.3	1.7°	336	30.9
Tangent Distance	152'	2191	33.3	122'	331	30.4
Sight Distance	760'	2191	33.3	--	--	--
Right Guardrail - Length	150'	3233	49.2	264'	840	77.2
Left Guardrail - Length	146'	3390	51.6	107'	535	49.2
Median Barrier - Presence	--	--	--	--	24	2.2

present in nearly a third of the approaches, but only on 6.1 percent of the bridges. The tangent distance averages 163 feet with ample sight distance. Approach guardrails are present for only about half of the bridges with lengths averaging 150 feet.

For two-lane divided twin structures, the average approach roadway width is nearly 40 feet with 12-foot lanes while the bridge roadway width is slightly narrower at 36.8 feet. Shoulders are present in almost all bridges and their approaches. The shoulder widths average 9.6 feet on the right and 5.7 feet on the left for the approaches and narrow to 7.7 feet on the right and 5.2 feet on the left for the bridges. Approximately 14 percent of the approaches have curbs while 65.5 percent of the bridges have curbs. Curves are present in about 30 percent of the approaches and 16.8 percent of the bridges, but the degree of curvature is very gentle. Approach guardrails are used on almost all approaches to the bridges (i.e., Approach 1), but less so on the approaches away from the bridge (i.e., Approach 2).

5.3.3 Bridge Narrowness Characteristics

Descriptive bridge narrowness statistics were generated concerning the weighted 1,088 divided and 6,574 undivided bridges in the SAMPLE file. Statistical tables are included in Appendix K. Salient features from these tables follow.

Table 42 illustrates the narrowness categories for both the undivided and divided bridges. Only slightly over half (52.6%) of the undivided bridges are wider than 24 feet with 12.1 percent 20 feet wide or less. It should be noted that over 20 percent of undivided bridges have no approach shoulders. For bridges with widths of 24 feet or less, the percentage with no approach shoulders increases to 32.9 percent. This presents a problem with the narrowness definitions based on shoulder reduction since there are no approach shoulders and thus no shoulder reduction. Bridges with no approach shoulders are therefore treated as separate narrowness categories for analysis purposes.

As for divided bridges, the majority of the divided bridges (53.4%) are wider than 24 feet with no shoulder reduction. There are very few divided bridges that are 24 feet or less in width or with no approach shoulders. The remaining bridges are wider than 24 feet and are evenly split between 1-50 percent shoulder reduction (22.6%) and greater than 50 percent shoulder reduction (21.8%).

TABLE 42

DISTRIBUTION OF SAMPLE BRIDGES BY NARROWNESS CATEGORY

Narrowness Category	Frequency	Percent
TWO-LANE UNDIVIDED STRUCTURES		
≤ 20.0 ft.		
Shoulder Reduction	416	6.3
No Shoulder Reduction	53	0.8
No Approach Shoulder	330	5.0
20.1-22.0 ft.		
Shoulder Reduction	267	4.1
No Shoulder Reduction	43	0.7
No Approach Shoulder	127	1.9
22.1-24.0 ft.		
Shoulder Reduction	931	14.2
No Shoulder Reduction	379	5.8
No Approach Shoulder	568	8.6
> 24.0 ft.		
> 50% Shoulder Reduction	998	15.2
1-50% Shoulder Reduction	769	11.7
No Shoulder Reduction	1,375	20.9
No Approach Shoulder	316	4.8
Unknown	2	--
TOTAL	6,574	100.0
TWO-LANE DIVIDED TWIN STRUCTURES		
≤ 24 ft.	20	1.8
> 24 ft.		
> 50% Shoulder Reduction	237	21.8
1-50% Shoulder Reduction	246	22.6
No Shoulder Reduction	580	53.4
No Approach Shoulder	3	0.3
Unknown	1	--
TOTAL	1,088	100.0

Tables A.90 and A.91 how the distributions of the bridges by federal-aid system and narrowness category for undivided and divided roadways. Of the undivided roadway bridges, 82.2 percent are on federal-aid primary and secondary rural roads with less than 3.5 percent in urban areas. As expected, most (93.2%) of the divided structures are on interstate and federal-aid primary roads. Shoulder reduction is more common on urban divided bridges (61.2%) than on rural divided bridges (37.3%). However, almost all divided bridges 24 feet wide or less or with no approach shoulder are in rural areas.

The distributions of the bridges for undivided and divided highways by functional class and narrowness category are shown in Tables A.92 and A.93. Most (79.3%) of the undivided roadway bridges are on rural minor arterial and collector roads, with another 16.5 percent on rural major arterial roads. Of the divided roadway bridges, 31.4 percent are on urban interstates and major arterials, and 62.8 percent are on rural interstates and major arterials. As expected, most of the bridges with widths of 24 feet or less are on collectors while the wider bridges are on arterials. However, as far as shoulder reduction is concerned, there does not appear to be any distinct pattern among the various functional classes.

Tables A.94 and A.95 show the distributions of the bridges by bridge length and narrowness category. For the undivided structures, 87.3 percent of the bridges are less than 300 feet long, of which only 27.2 percent are non-narrow (> 24 feet wide with no shoulder reduction). Of the divided roadway bridges, 75.6 percent are less than 300 feet long, 40.8 percent of which are narrow (≤ 24 feet wide or with shoulder reduction).

Distributions of the bridges by 1977 ADT and narrowness category are shown in Tables A.96 and A.97. For the undivided structures, 90.1 percent have ADT's of less than 4,000 vehicles per day with only 24.9 percent of them in the non-narrow categories. For the divided structures, 81.2 percent have ADT's of greater than 4,000 vehicles per day, 49.7 percent of which are non-narrow. It is interesting to note that the percentage of bridges with no shoulder reduction decreases with increasing ADT, indicating that bridges carrying higher traffic volume are likely to be in urban areas and thus older and narrower.

Table A.98 shows the distribution of Bridge Safety Index (BSI) for the various bridge narrowness categories. The BSI was developed[11,17] as a simple means of measuring the relative hazard or safety between different bridges. This concept of a single index is very appealing from an operational standpoint though its appropriateness and applicability remain to be seen. It should be noted that two of the BSI factors on volume/ capacity ratio and traffic mix are not included in the index. However, since they account for only 10 percent of the index, the BSI used in this study is considered as a close approximation of the index with all 10 factors.

The general trend for undivided bridges is for the BSI to increase with wider bridge roadway widths, ranging from a low of 49.5 average for bridges 20 feet or narrower to a high of 76.0 average for bridges wider than 24 feet. However, the BSI does not appear to be significantly affected by the presence/absence of approach shoulder or shoulder reduction. For divided bridges, the BSI also increases with wider bridge width but increases with decrease in shoulder reduction as well. The BSI is much lower for bridges with no approach shoulders, but the sample size is too small to attach any significance to this trend.

Average values of selected bridges and approach characteristics for bridges with and without accidents in each of the 18 narrowness categories are summarized in Table 43. Several trends are evident from the data:

1. The average daily traffic (ADT) for bridges with accidents is much higher than that for bridges without accidents.

2. The average lengths of bridges with accidents are much greater than those without accidents, especially for bridges with shoulder reduction or no approach shoulder.

3. Bridge roadway widths are similar for bridges with or without accidents while approach shoulder widths are somewhat greater for bridges with accidents than for bridges without accidents. More significantly, approach shoulder widths for undivided bridges with no shoulder reduction are much smaller than those for bridges with shoulder reduction. This raises the question of whether the definitions on bridge narrowness as used in this study are appropriate or not since shoulder reduction is more a function of the approach shoulder width than an indication of the bridge narrowness.

4. For undivided bridges, those with accidents are more likely to have curved horizontal alignment both on the bridge and in the approaches.

TABLE 43

SELECTED BRIDGE AND APPROACH CHARACTERISTICS BY NARROWNESS CATEGORY AND ACCIDENT OCCURRENCE

Narrowness Category		Bridge Length (ft.)		Bridge Roadway Width (ft.)		Approach Shoulder Width (ft.)		Bridge Horizontal Alignment				Approach Horizontal Alignment						ADT	
								% Curve		° Curvature		% Curve		° Curvature		Tangent Distance (ft.)			
Bridge Width	Shoulder Reduction	No Acc	Acc	No Acc	Acc	No Acc	Acc	No Acc	Acc	No Acc	Acc	No Acc	Acc	No Acc	Acc	No Acc	Acc	No Acc	Acc
								UNDIVIDED BRIDGES											
≤ 20.0'	Yes	87	364	19.1	19.6	7.7	9.5	3.3	1.8	1.7	18.1*	61.5	76.4	5.0	11.0	138	119	390	2,034
	No**	74	93	19.0	19.5	2.0	2.0	6.0	0.0	3.8	--	66.0	50.0	5.5	9.8	127	0	472	601
	N/A	122	119	18.8	19.2	--	--	0.9	8.6	1.3*	5.3*	70.0	75.3	7.4	6.0	145	147	338	1,758
20.1'-22.0'	Yes	110	288	21.7	21.6	7.5	10.5	0.0	12.7	--	8.6	37.7	40.8	3.5	10.2	175	31	450	3,260
	No**	158	88	21.8	22.0	2.4	2.0	0.0	0.0	--	--	42.9	0.0	5.5	--	262	--	463	5,859
	N/A	100	181	21.4	21.5	--	--	9.2	0.0	0.3	--	14.2	48.6	1.5	5.3*	189	0*	446	6,272
22.1'-24.0'	Yes	138	270	23.5	23.7	8.7	11.1	6.0	16.5	3.0	5.5	39.4	70.7	5.3	5.7	132	128	549	3,454
	No	107	196	23.7	23.9	3.1	2.5	2.2	5.1	2.0	3.1*	41.1	74.5	4.8	5.3	112	153	494	2,443
	N/A	177	217	23.4	23.6	--	--	0.0	11.3	--	1.1*	43.7	30.9	3.0	3.0	124	50	383	3,005
> 24.0'	> 50%	274	312	29.3	27.9	13.1	16.5	5.1	13.5	2.2	4.5	49.4	54.2	3.2	5.7	135	131	1,401	4,568
	1-50%	145	153	34.8	34.4	14.6	15.5	4.1	14.7	4.6	2.4	26.3	47.8	2.4	3.3	204	129	1,676	3,772
	No	149	166	34.1	37.5	9.5	12.9	6.0	18.2	2.1	3.6	45.8	53.0	3.4	5.5	176	113	1,475	4,500
	N/A	144	296	31.1	29.7	--	--	4.5	7.7	3.5	4.1*	62.1	76.9	3.6	4.4	140	90	729	3,277
								DIVIDED BRIDGES											
≤ 24.0'	--	245	500	24.0	23.0	14.8	11.4	0.0	0.0	--	--	60.0	26.4	3.4*	2.5*	172*	83*	5,866	8,802
> 24.0'	> 50%	273	367	28.3	28.1	14.3	15.6	32.3	15.0	1.5	2.0	66.5	52.0	3.4	2.2	130	163	8,012	17,479
	1-50%	248	224	37.6	37.8	17.1	16.7	22.4	22.0	1.4	1.9	39.1	49.8	1.9	1.6	46	144	7,433	12,263
	No	200	199	40.2	40.6	14.3	14.7	15.1	15.3	1.4	1.8	38.7	36.1	1.3	1.8	92	128	5,473	12,209
	N/A****	375	420	28.0	33.0	--	--	0.0	0.0	--	--	0.0	0.0	--	--	--	--	3,726	9,676

Note. * The sample size for this variable is less than 5.
** There are only two bridges with accidents in this narrowness category.
*** There is only one bridge with accidents in this narrowness category.
**** There are only three bridges in this narrowness category.

Also, bridges with accidents tend to have greater degree of curvature and shorter tangent distances. For divided bridges, the horizontal alignment is so gentle that it has very little effect on accident occurrences.

5.4 Accident Rates and Severity

This section presents the average accident frequency, rate, and severity for selected bridge and approach features. Detailed statistical analyses on their relationships will be described in Chapter VI. Discussions in this section are more descriptive and cursory in nature.

Accident frequency is expressed in terms of number of accidents per year per bridge (Acc/Yr/Br) while number of accidents per million vehicles (Acc/10^6 Veh) is used as the accident rate to account for traffic volume as an exposure measure. Accident severity is described by the average accident cost per accident ($/Acc), which is computed based on the following unit costs for the various injury levels for the highest occupant injury, as published by the National Safety Council[(1)]:

PIC	Description	Unit Cost
0	No Injury	$ 980
C	Possible Injury	1,100
B	Non-Incapacitating Injury	4,400
A	Incapacitating Injury	14,700
K	Fatality	170,000

The results are presented as tables in this section for the key bridge and approach features and tables for other selected bridge and approach characteristics are included in Appendix L.

Tables A.99 and A.100 summarize the accident rates and severities by federal-aid systems and functional class. As expected, the accident frequencies and rates are similar to those of the POPULATION file (see Chapter III, Table 14). The accident frequencies on urban bridges (2.46 accidents per year per bridge) are much higher than those on rural bridges (0.40 accident per year per bridge), reflecting higher traffic volumes in urban areas. The accident rates are also higher for urban bridges, but to a much lesser extent (0.63 vs. 0.40 accident per million vehicles for urban vs. rural bridges). Accident frequencies decrease with lower highway types, i.e., highest for interstate highways and lowest for collector roadways. As for accident rates, minor arterials have the highest accident rate, followed by major arterials and interstate highways with collector roadways having the lowest accident rate.

The severities of accidents are higher in rural areas ($6,703 per accident) than in urban areas ($4,318 per accident), reflecting higher operating speeds and greater percentage of single vehicle accidents in rural areas. However, there are no apparent differences between the various highway types in urban or rural areas. Federal-aid secondary highways have an exceptionally high cost per accident while urban collector roadways have a significantly lower cost per accident. There are no apparent explanations for such variations except that the sample sizes are very small in both categories.

5.4.1 Accident Frequency and Rate

Table 44 summarizes the average accident frequencies and rates of the bridges by narrowness category. The following observations may be drawn from the data:

1. The percentage of divided bridges with accidents (66.8%) is more than three times higher than that of undivided bridges (20.0%). The average accident frequency for all divided bridges is 1.74 accidents per year per bridge which is nearly five times that of undivided bridges at 0.36 accident per year per bridge. As for accident rate, there is very little difference, indicating that the difference in accident frequency is mainly due to higher traffic volume on divided bridges. However, when only bridges with accidents are included, the accident frequency for divided bridges is only slightly higher than that of undivided bridges (2.61 vs. 1.79), but much lower in terms of accident rate (0.72 vs. 2.02). This of course reflects the higher percentage of bridges with accidents for divided bridges.

2. The percentage of bridges with accidents increases with greater shoulder reduction. The same is true for accident frequency and rate. For instance, for undivided bridges greater than 24 feet in width, only 8.2 percent of the bridges with no approach shoulders have accidents with an average accident frequency of 0.11 accident per year and 0.186 accident per million vehicles. The corresponding figures for bridges with no shoulder reduction are 22.0 percent, 0.402 accident per year per bridge, and 0.41 accident per million vehicles,

TABLE 44

DISTRIBUTION OF BRIDGES WITH ACCIDENTS BY NARROWNESS CATEGORY

Narrowness Category	Total No. of Bridges	Bridges With Accidents		All Bridges		Bridges With Accidents	
		No.	%	Acc/Yr/Br	Acc/10^6 Veh	Acc/Yr/Br	Acc/10^6 Veh
TWO-LANE UNDIVIDED SINGLE STRUCTURES							
≤ 20', Shoulder Reduction	416	55	13.2	0.231	0.469	1.75	3.55
≤ 20', No Shoulder Reduction	52	2	3.8	0.063	0.368	1.65	9.58
≤ 20', No Approach Shoulder	330	13	3.9	0.053	0.195	1.35	4.95
20.1'-22', Shoulder Reduction	267	55	20.6	0.459	0.595	2.23	2.89
20.1'-22', No Shoulder Reduction	43	1	2.3	0.030	0.016	1.30	0.67
20.1'-22', No Approach Shoulder	127	9	7.1	0.121	0.072	1.71	1.01
22.1'-24', Shoulder Reduction	931	198	21.3	0.479	0.491	2.25	2.31
22.1'-24', No Shoulder Reduction	379	21	5.5	0.078	0.126	1.40	2.27
22.1'-24', No Approach Shoulder	568	16	2.8	0.047	0.116	1.66	4.11
> 24', > 50% Shoulder Reduction	998	384	38.5	0.635	0.585	1.65	1.52
> 24', 1-50% Shoulder Reduction	769	232	30.2	0.489	0.540	1.62	1.79
> 24', No Shoulder Reduction	1,375	302	22.0	0.402	0.413	1.83	1.88
> 24', No Approach Shoulder	316	26	8.2	0.106	0.186	1.29	2.26
	6,571	1,314	20.2	0.358	0.403	1.79	2.02
TWO-LANE DIVIDED TWIN STRUCTURES							
≤ 24'	19	14	73.7	1.886	0.604	2.56	0.82
> 24', > 50% Shoulder Reduction	237	208	87.8	2.808	0.606	3.20	0.69
> 24', 1-50% Shoulder Reduction	246	197	80.1	1.978	0.649	2.47	0.81
> 24', No Shoulder Reduction	580	305	52.6	1.157	0.358	2.20	0.68
> 24', No Approach Shoulder	3	1	33.3	1.333	0.397	4.00	1.19
	1,085	725	66.8	1.742	0.481	2.61	0.72

increasing to 38.5 percent, 0.64 accident per year per bridge, and 0.59 accident per million vehicles for bridges with greater than 50 percent shoulder reduction. The differences in accident frequency and rate are again caused by the differences in percentage of bridges with accidents since such a trend is not evident for only bridges with accidents.

3. For undivided bridges, the percentage of bridges with accidents and accident frequency for all bridges increases with greater bridge widths while the accident rate remains little changed. Actually, when only bridges with accidents are considered, the accident frequency is similar for differing bridge widths while the accident rate decreases with increasing bridge width. Again, this reflects the difference in percentage of bridges with accidents and traffic volume.

The average accident frequencies and rates by bridge length, bridge width, and percent shoulder reduction are shown in Tables A.101 through A.103. It is evident from the data that both accident frequency and rate increase with greater bridge lengths. On the other hand, bridge widths have little effect on accident frequencies or rates. Undivided bridges less than 24 feet in width exhibit lower accident frequencies and rates than bridges wider than 24 feet. Overall, the general trend, though very weak, is for the accident frequency and rate to decrease with increasing bridge width. Bridges with no shoulder reduction or no approach shoulder have lower accident frequencies and rates than bridges with shoulder reduction. There is also a trend indicating higher accident frequency and rate for bridges with greater percentage of shoulder reduction.

Tables A.104 and A.105 show the average accident frequencies and rates by bridge horizontal and vertical alignments. Bridges with curved alignment have much higher accident frequencies and rates than bridges with straight alignment, especially for undivided bridges. Also, accident frequencies and rates are higher for bridges with left curves than those with right curves and increase with greater degree of curvature. The effects of vertical alignment on accident frequencies and rates are not as obvious. Bridges on grades or vertical curves generally have slightly higher accident frequencies and rates than level bridges. However, when the bridge maximum vertical grade is considered, it is clear that accident frequencies and rates increase with greater percent grade for both upgrades and downgrades.

Average accident frequencies and rates by approach horizontal and vertical alignments are shown in Tables A.106 through A.109. Again, there is a strong trend indicating that accident frequencies and rates are higher for bridges with curved approaches than those with straight approaches and increase with greater degree of curvature. For undivided bridges, there is a weak trend suggesting that accident frequencies and rates increase with shorter tangent distance (i.e., distance from end of approach curve to beginning of bridge) and reduced sight distance, but such trend is not present with divided bridges. Approach vertical alignment appears to have little effect on accident frequencies and rates, except for downgrades of steeper than 6 percent for undivided bridges and 4 percent for divided bridges which exhibit higher accident frequencies and rates.

Table A.110 illustrates the accident frequencies and rates by selected approach conditions, including roadside distraction, signing, longitudinal marking, delineator/object marker and approach guardrail. There is a strong trend indicating that accident frequencies and rates increase drastically with increasing degree of roadside distraction. Part of the strong correlation may be explained by the fact that roadside developments are directly proportional to traffic volume so that roadways with high degree of roadside distraction are also associated with higher traffic volumes and more frequent access points and potential conflicts.

As for the other approach conditions relating to traffic control devices that are potential low-cost safety countermeasures, there is also a strong trend, but contrary to expectation, that accident frequencies and rates are higher for bridges with warning and/or no passing signs, longitudinal marking, and delineator/object marker than for bridges without. The only plausible explanation is that such traffic control devices are installed at bridges with higher traffic volumes and/or with past accident experience. In other words, this is a reflection on where such traffic control devices are being used and not an indication of their effectiveness on reducing accident occurrence. Unfortunately, this also precludes any evaluation on their effectiveness as potential low-cost safety countermeasures. A different experimental design, such as a before-after-with-control design, will be more appropriate to evaluate their effectiveness.

The same can be said of approach guardrail presence/absence, but the results are less clear. For undivided bridges, those with no approach guardrail have the lowest accident frequency and rate, while those with partial approach guardrails have the highest. For divided bridges, those with no approach guardrails have the highest accident frequency while those with complete approach guardrails have the lowest. However, there are only 44 out of 1,087 divided bridges that have no or partial approach guardrails. Again, no effectiveness evaluation can be made regarding the installation of approach guardrails as a potential safety countermeasure.

Table 45 shows the average accident frequencies and rates for various ADT ranges. As expected, ADT is strongly correlated with accident frequency, i.e., higher accident frequency is associated with greater ADT. However, the relationship between ADT and accident rate is very weak since ADT is already taken into account as an exposure measure. The weak trends suggest that accident rate increases with higher ADT for undivided bridges, but decreases with greater ADT for divided bridges.

It is interesting to note that both accident frequency and rate decrease with higher speed limits, as shown in Table A.111. However, the results should be tempered by the fact that the majority (80% for undivided and 95% of divided bridges) of the bridges have a speed limit of 55 mph.

Finally, accident frequencies and rates generally decrease with increasing BSI values, as shown in Table A.112. Since increasing BSI values are presumably associated with safer or less hazardous bridges, the BSI index seems to provide some indication as to the accident frequencies and rates. However, the relationships are rather weak, especially for undivided bridges.

5.4.2 Accident Severity

The relationships of accident severity with the same set of selected bridge and approach characteristics are examined in this subsection and shown in Tables 46 and 47 and Tables A.113 through

TABLE 45

ACCIDENT FREQUENCIES AND RATES BY AVERAGE DAILY TRAFFIC

Average Daily Traffic	Undivided			Divided		
	N	Acc/Yr/Br	Acc/10^6 Veh	N	Acc/Yr/Br	Acc/10^6 Veh
1-399	2,314	0.0057	0.075	--	--	--
400-999	1,663	0.077	0.353	13	0	0
1,000-1,999	979	0.337	0.674	42	0.368	0.642
2,000-2,999	586	0.599	0.711	49	0.777	0.908
3,000-3,999	377	0.916	0.776	98	0.549	0.444
4,000-4,999	232	1.379	0.921	82	0.700	0.438
5,000-7,999	307	1.464	0.653	240	0.968	0.444
8,000-11,999	69	2.686	0.840	211	1.896	0.561
12,000-15,999	32	5.566	1.241	117	2.350	0.492
16,000-19,999	12*	4.093	0.462	90	2.324	0.367
20,000-24,999	--	--	--	54	3.298	0.424
25,000-34,999	--	--	--	46	3.109	0.321
35,000-49,999	--	--	--	27	4.316	0.308
≥ 50,000	--	--	--	12	13.328	0.653

* Note. This includes bridges with ADT ≥ 16,000.

TABLE 46

ACCIDENT SEVERITIES BY NARROWNESS CATEGORY

Narrowness Category			
Bridge Width	Shoulder Reduction	Sample Size	Accident Cost Per Accident
	UNDIVIDED BRIDGES		
≤ 20.0'	Yes	288	$4,670
	No	11	2,860
	N/A	54	2,635
20.1'-22.0'	Yes	365	7,961
	No	4	1,835
	N/A	44	3,399
22.1'-24.0'	Yes	1,337	7,003
	No	89	7,604
	N/A	80	6,636
> 24.0'	> 50%	1,900	7,244
	1-50%	1,124	5,406
	No	1,619	5,047
	N/A	101	2,023
	Subtotal	7,016	$6,181
	DIVIDED BRIDGES		
< 24.0'	--	110	$7,095
> 24.0'	> 50%	2,001	6,526
	1-50%	1,452	4,090
	No	1,971	5,774
	N/A	13	2,298
	Subtotal	5,547	$5,623
	TOTAL	12,563	$5,935

TABLE 47

ACCIDENT SEVERITIES BY AVERAGE DAILY TRAFFIC

Average Daily Traffic	Undivided		Divided	
	N	$/Acc	N	$/Acc
1-399	36	7,979	--	--
400-999	385	6,789	--	--
1,000-1,999	992	5,922	42	2,615
2,000-2,999	1,038	7,687	105	2,573
3,000-3,999	1,032	6,973	161	9,501
4,000-4,999	941	6,096	172	3,886
5,000-7,999	1,343	5,526	698	8,911
8,000-11,999	554	6,934	1,204	5,115
12,000-15,999	538	3,482	831	3,700
16,000-19,999	152*	3,216	608	3,854
20,000-24,999	--	--	536	8,393
25,000-34,999	--	--	406	5,683
35,000-49,999	--	--	359	6,683
≥ 50,000	--	--	499	3,530

* Note. This includes bridges with ADT ≥ 16,000.

A.124 in Appendix L. Overall, there is a general lack of strong relationships between accident severity and the selected characteristics. Some of the more interesting relationships are discussed as follows.

The average severity of accidents on divided bridges ($5,623 per accident) is slightly less than that on undivided bridges ($6,181 per accident), as shown in Table 45. Bridges with shoulder reduction generally have higher severity than bridges with no shoulder reduction or no approach shoulders. The severity of accidents decreases with increasing bridge width for undivided bridges with the exception of bridges 20 feet or less which have the lowest severity.

Accident severities increase with greater bridge lengths, but decrease with greater bridge widths. Bridges with no approach shoulders or no shoulder reduction have lower severity than those with shoulder reduction, and the severity increases with greater percentage of shoulder reduction. Accidents on straight bridges and approaches appear to be more severe than those on curves while the severity increases with greater tangent and sight distances. Accidents on level bridges and approaches also seem to be slightly more severe than those on grades with the exception of sag for divided bridges.

Roadside distraction is one of the very few characteristics that has a strong association with accident severity. Accident costs per accident decrease with increasing level of roadside distraction, perhaps as a result of lower operating speed and more cautious driving. Accident severity is higher for undivided bridges with no signing, but with longitudinal marking and delineator/object marker. As for divided bridges, bridges with warning signs have the highest severity while those with no passing signs have the lowest. Also, divided bridges with no longitudinal marking, but with delineator/object marker and approach guardrail have higher accident costs per accident.

Accident severity of undivided bridges decreases slightly with increase in ADT, as shown in Table 47. The reverse seems to be the case for divided bridges, but the trend is too weak for any significance. On the other hand, higher speed limits are associated with greater accident severity as one may expect with the higher operating speeds. Also, higher BSI values are associated with greater accident severity, particularly for divided bridges.

It should be reemphasized that the relationships described in this subsection on accident severity, except as noted, are generally very weak and are likely to be insignificant.

5.5 Bridge Accident Characteristics

The distributions of first harmful event, manner of collision for vehicle-to-vehicle impacts, and object struck for single vehicle fixed-object accidents by various selected environmental, bridge, and approach characteristics are examined in this section with appropriate tables presented in Appendix L.

The first harmful event is grouped into four general categories as follows:

1. Collision with another vehicle
2. Impact with a fixed object
3. Vehicle overturned, i.e., rollover
4. Other

For collisions with another vehicle, the manner of collison is further classified into the following four groups:

1. Opposite direction conflict, i.e., head-on and sideswipe-opposite direction
2. Same direction conflict, i.e., rear-end and sideswipe-same direction
3. Angle conflict
4. Other

Similarly, the object struck for fixed-object impacts is grouped into four types as follows:

1. Bridge rail
2. Bridge end/abutment, i.e., bridge rail or parapet end
3. Guardrail/median barrier
4. Other fixed object

5.5.1 General Accident Characteristics

The distributions of first harmful event by time of accident and ambient conditions are shown in Tables A.125 through A.128. Collisions with another vehicle are more prevalent on weekdays while fixed object impacts and rollovers are more frequent on weekends. Accident frequencies are highest on Friday (17.5%), followed by Saturday (17.3%) and Sunday (15.9%). Accident frequencies on weekdays are somewhat lower, ranging from 11.7 percent on Tuesday to 13.3 percent on Thursday.

Collisions with another vehicle are highest during the evening rush hours while fixed object impacts and rollovers are predominant during early morning and late evening hours. Fifty-three percent of accidents during daylight hours involve collisions with another vehicle while 32.2 percent are fixed object impacts. In comparison, 52.1 percent of accidents during hours of darkness involve fixed object impacts while collisions with another vehicle account for only 25.1 percent.

Nearly 70 percent of collisions with another vehicle occur on dry pavements. In comparison, nearly 45 percent of fixed object impacts occur during inclement weather, especially when the road surface is covered with snow or ice. The results are expected considering that bridges are more susceptible to icing.

As shown in Table 48, fixed object impacts have the highest severity for undivided bridges with 14.0 percent result in incapacitating (A) or fatal (K) injuries, followed by rollovers (11.3% K + A injuries) and collisions with another vehicle (9.9% K + A injuries). For divided highways, rollovers are the most severe (15.0% K + A injuries), followed by fixed object impacts (10.6% K + A injuries). Collisions with another vehicle are much lower in severity with only 5.7 percent K + A injuries.

In terms of object struck, as shown in Table A.129, bridge end/abutment is unquestionably the most severe with 8.8 to 11.6 percent resulting in fatal injuries for divided and undivided bridges, respectively, compared to an overall average of just over two percent. Impacts with guardrail or median barrier are higher in severity (15.4% K + A injuries) than those with bridge rail (10.6% K + A injuries) for undivided bridges, but much lower for divided bridges (6.9% vs. 10.9% K + A injuries). The severity of impacts with other fixed objects is similar between undivided and divided bridges with slightly over 11 percent of K + A injuries.

Table A.130 illustrates the distribution of injury severity by manner of collision. As expected, opposite direction conflicts are the most severe with 7.1 to 12.7 percent resulting in fatal injuries compared

TABLE 48

DISTRIBUTION OF INJURY SEVERITY BY FIRST HARMFUL EVENT

	Highest Injury Severity (PIC)											
	O		C		B		A		K		Total	
First Harmful Event	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
UNDIVIDED BRIDGES												
Another Vehicle	1,953	65.2	386	12.9	362	12.1	235	7.8	62	2.1	2,998	42.8
Fixed Object	1,521	58.6	217	8.4	495	19.1	303	11.7	60	2.3	2,595	37.0
Overturned	251	48.5	68	13.2	140	27.1	50	9.6	9	1.7	519	7.4
Other	751	83.8	50	5.6	57	6.4	25	2.8	13	1.5	897	12.8
Total	4,477	63.9	722	10.3	1,054	15.0	613	8.7	144	2.1	7,009	100.0
DIVIDED BRIDGES												
Another Vehicle	1,531	69.3	301	13.6	252	11.4	101	4.6	24	1.1	2,209	39.4
Fixed Object	1,590	63.1	257	10.2	406	16.1	208	8.3	59	2.3	2,520	44.9
Overturned	212	51.0	52	12.5	81	19.5	56	13.4	15	3.6	417	7.4
Other	379	82.0	28	6.1	35	7.6	11	2.5	8	1.8	463	8.3
Total	3,713	66.2	639	11.4	774	13.8	376	6.7	106	1.9	5,609	100.0

to an average of 2.0 and 1.0 percent for undivided and divided bridges, respectively. Same direction conflicts have the lowest severity with under 4.5 percent of K + A injuries. The high proportion of same direction conflict for divided bridges explains the low severity of collisions with another vehicle on divided bridges as compared to undivided bridges.

Some questions may be raised regarding the presence of opposite direction and angle conflicts on divided bridges. These may include wrong way travel and vehicle spinouts so that the impact configuration resembles that of opposite direction or angle conflicts. It is not possible to verify if such assumptions are correct or not based on computerized police level accident data.

5.5.2 Bridge and Approach Characteristics

Tables 49 through 51 summarize the distributions of first harmful event, manner of collision, and object struck by narrowness category. The following observations may be drawn from the data:

1. There are more collisions with another vehicle and less fixed object impacts for undivided bridges as compared to divided bridges.

2. There is a weak trend suggesting that, with greater bridge width and less shoulder reduction, the percentage of collisions with another vehicle decreases while the percentages of fixed object impacts and rollovers will increase. The trend is more evident for divided bridges than for undivided bridges.

3. The percentage of opposite direction conflicts seems to decrease with greater bridge width. Otherwise, the data for manner of collision is too scattered for any observed trends.

4. The percentage of guardrail/median barrier impacts is lower (20.8% vs. 41.7%) while that of collisions with other fixed objects is higher (40.2% vs. 24.3%) for undivided bridges than for divided bridges. This reflects the extensive use of approach guardrail and presence of median barrier for divided bridges. On the other hand, the roadsides of divided highways are less cluttered with fixed objects and thus a lower proportion of impacts with other fixed objects. Also, the percentages of impacts with bridge rail and bridge end/abutment are slightly lower for undivided bridges.

The distributions of first harmful event by bridge length, bridge width, and percent shoulder reduction are shown in Tables A.131 through

TABLE 49

DISTRIBUTION OF FIRST HARMFUL EVENT BY NARROWNESS CATEGORY

Narrowness Category		First Harmful Event									
		Another Vehicle		Fixed Object		Overturned		Other		Total	
Bridge Width	Shoulder Reduction	No.	%	No.	%	No.	%	No.	%	No.	%
		UNDIVIDED BRIDGES									
≤ 20.0'	Yes	117	40.6	142	49.3	20	6.9	9	3.1	288	100.0
	No	2	20.0	6	60.0	1	10.0	1	10.0	10	100.0
	N/A	15	28.8	30	57.7	4	7.7	3	5.8	52	100.0
20.1'-22.0'	Yes	174	47.9	150	41.3	23	6.3	16	4.4	363	100.0
	No	4	100.0	0	0.0	0	0.0	0	0.0	4	100.0
	N/A	32	72.7	8	18.2	4	9.1	0	0.0	44	100.0
22.1'-24.0'	Yes	574	43.0	525	39.4	90	6.7	145	10.9	1,334	100.0
	No	36	40.9	29	33.0	14	15.9	9	10.2	88	100.0
	N/A	34	43.0	30	38.0	5	6.3	10	12.7	79	100.0
> 24.0'	> 50%	745	39.3	786	41.4	131	6.9	236	12.4	1,898	100.0
	1-50%	465	41.7	379	34.0	82	7.4	189	17.0	1,115	100.0
	No	742	45.7	488	30.1	134	8.3	258	15.9	1,622	100.0
	N/A	55	54.5	16	15.8	9	8.9	21	20.8	101	100.0
Subtotal		2,995	42.8	2,589	37.0	517	7.4	897	12.8	6,998	100.0
		DIVIDED BRIDGES									
≤ 24.0'	--	34	30.6	62	55.9	4	3.6	11	9.9	111	100.0
> 24.0'	> 50%	704	35.3	1,044	52.3	114	5.7	133	6.7	1,995	100.0
	1-50%	514	35.6	681	47.1	119	8.2	131	9.1	1,445	100.0
	No	882	45.0	721	36.8	177	9.0	180	9.2	1,960	100.0
	N/A	2	16.7	5	41.7	2	16.7	3	25.0	12	100.0
Subtotal		2,136	38.7	2,513	45.5	416	7.5	458	8.3	5,523	100.0
Total		5,131	41.0	5,102	40.7	933	7.5	1,355	10.8	12,521	100.0

TABLE 50

DISTRIBUTION OF MANNER OF COLLISION BY NARROWNESS CATEGORY

Narrowness Category		Manner of Collision								Total	
		Opposite Dir. Conflict		Same Dir. Conflict		Angle Conflict		Other			
Bridge Width	Shoulder Reduction	No.	%	No.	%	No.	%	No.	%	No.	%
UNDIVIDED BRIDGES											
≤ 20.0'	Yes	34	29.1	27	23.1	25	21.4	31	26.5	117	3.8
	No	0	0.0	1	50.0	1	50.0	0	0.0	2	0.1
	N/A	3	21.4	5	35.7	1	7.1	5	35.7	14	0.5
20.1'-22.0'	Yes	37	21.1	47	26.9	25	14.3	66	37.7	175	5.6
	No	0	0.0	0	0.0	1	25.0	3	75.0	4	0.1
	N/A	7	22.6	4	12.9	10	32.3	10	32.3	31	1.0
22.1'-24.0'	Yes	140	22.4	175	28.0	86	13.8	223	35.7	624	20.1
	No	15	42.9	13	37.1	6	17.1	1	2.9	35	1.1
	N/A	4	12.5	17	53.1	0	0.0	11	34.4	32	1.0
> 24.0'	> 50%	135	17.6	256	33.3	93	12.1	285	37.1	769	24.8
	1-50%	85	17.6	112	23.2	90	18.7	195	40.5	482	15.6
	No	112	14.8	300	39.5	94	12.4	253	33.3	759	24.5
	N/A	7	12.7	6	10.9	15	27.3	27	49.1	55	1.8
Total		579	18.7	963	31.1	447	14.4	1,110	35.8	3,099	100.0
DIVIDED BRIDGES											
≤ 24.0'	--	0	0.0	24	72.7	6	18.2	3	9.1	33	1.5
> 24.0'	> 50%	55	7.5	499	68.0	66	9.0	114	15.5	734	32.6
	1-50%	15	2.7	389	70.9	38	6.9	107	19.5	549	24.4
	No	29	3.1	457	48.9	207	22.1	242	25.9	935	41.5
	N/A	0	0.0	2	100.0	0	0.0	0	0.0	2	0.1
Total		99	4.4	1,371	60.9	317	14.1	466	20.7	2,253	100.0

TABLE 51

DISTRIBUTION OF OBJECT STRUCK BY NARROWNESS CATEGORY

Narrowness Category		Object Struck									
		Bridge Rail		Bridge End/ Abutment		Guardrail/ Median Barrier		Other Fixed Object		Total	
Bridge Width	Reduction	No.	%	No.	%	No.	%	No.	%	No.	%
UNDIVIDED BRIDGES											
≤ 20.0'	Yes	68	48.2	10	7.1	20	14.2	43	30.5	141	5.4
	No	0	0.0	1	14.3	0	0.0	6	85.7	7	0.3
	N/A	16	55.2	3	10.3	4	13.8	6	20.7	29	1.1
20.1'-22.0'	Yes	57	43.5	11	8.4	31	23.7	32	24.2	131	5.0
	No	--	--	--	--	--	--	--	--	0	0.0
	N/A	2	33.3	0	0.0	0	0.0	4	66.7	6	0.2
22.1'-24.0'	Yes	172	32.6	54	10.2	86	16.3	216	40.9	528	20.3
	No	5	17.9	7	25.0	6	21.4	10	35.7	28	1.1
	N/A	9	31.0	5	17.2	3	10.3	12	41.4	29	1.1
> 24.0'	> 50%	274	34.3	50	6.3	198	24.8	278	34.8	800	30.8
	1-50%	96	24.6	35	9.0	80	20.5	179	45.9	390	15.0
	No	111	22.8	23	4.7	113	23.2	241	49.4	488	18.8
	N/A	2	10.0	2	10.0	0	0.0	16	80.0	20	0.8
Total		812	31.3	201	7.7	541	20.8	1,043	40.2	2,597	100.0
DIVIDED BRIDGES											
≤ 24.0'	--	38	60.3	9	14.3	4	6.4	12	19.0	63	2.4
> 24.0'	> 50%	327	30.5	72	6.7	444	41.5	228	21.3	1,071	41.5
	1-50%	131	19.0	33	4.8	354	51.2	173	25.0	691	26.8
	No	211	28.1	54	7.2	273	36.4	213	28.4	751	29.1
	N/A	4	80.0	0	0.0	1	20.0	0	0.0	5	0.2
Total		711	27.5	168	6.5	1,076	41.7	626	24.3	2,581	100.0

A.133. Except for the weak trend of decreasing percentage of collisions with another vehicle and increasing percentage of fixed object impacts for bridges with greater bridge width and less shoulder reduction as discussed above on narrowness category, there are no other trends evident from the data.

Tables A.134 and A.135 show the distributions of first harmful event by bridge horizontal and vertical alignments. For undivided bridges, the percentage of collisions with another vehicle remains little changed between straight and curved alignment although the percentage does decrease with increasing degree of curvature for curved bridges. As for fixed object impacts, the percentage is higher for curved alignment and increases with greater degree of curvature. For divided bridges with curved alignment, the percentage of collisions with another vehicle is lower than that of bridges with straight alignment, but higher for fixed object impacts. However, in contrast to undivided bridges, the percentage of collisions with another vehicle increases and the percentage of fixed object decreases with greater degree of curvature.

Bridges with level grade have slightly lower percentage of collisions with another vehicle and somewhat higher percentage of fixed object impacts than bridges on grades or vertical curves. However, the differences are rather small and do not appear to be affected by the percent grade.

The distributions of first harmful event by approach horizontal and vertical alignments are shown in Tables A.136 through A.139. The only evident trend is the higher percentage of fixed object impacts associated with curved approaches which increases with greater degree of curvature. Otherwise, the approach horizontal and vertical alignments seem to have little effect on the distribution of first harmful event.

Table A.140 summarizes the distribution of first harmful event by selected approach conditions. There is a strong trend indicating that, as the degree of roadway distraction increases, the proportion of vehicle-to-vehicle collisions increases accompanied by a corresponding decrease in fixed object impacts. This is expected since higher degree of roadside distraction is associated with greater traffic volume and more frequent access points and potential conflicts.

Bridges with signing, delineator/object marker, and approach guardrail, but no longitudinal marking, tend to be associated with lower occurrence of collisions with another vehicle and higher incidences of fixed object impacts. However, as pointed out previously, this is simply a reflection on where such safety devices are installed and not an indication of a cause-and-effect relationship.

Speed limit appears to have little effect on the distribution of first harmful event except for the percentage of rollovers which shows a gradual increase with higher speed limit, as shown in Table A.141. The bridge safety index, as shown in Table A.142, also seems to have little relationship to the distribution of first harmful event.

The distribution of first harmful event is strongly affected by the average daily traffic, as shown in Table 52. With higher traffic volume, the proportion of vehicle-to-vehicle collisions will increase with corresponding decrease in the percentage of fixed object impacts and rollovers. Simple linear regression equations fitted to the data are shown as follows:

Undivided bridges

% Another Vehicle = 27.96 + 0.002435 (ADT) $R^2 = 0.90$

% Fixed Object = 45.85 - 0.001644 (ADT) $R^2 = 0.92$

% Overturned = 11.19 - 0.000634 (ADT) $R^2 = 0.78$

Divided Bridges

% Another Vehicle = 22.32 + 0.0008295 (ADT) $R^2 = 0.77$

% Fixed Object = 51.98 - 0.0004087 (ADT) $R^2 = 0.57$

% Overturned = 12.87 - 0.0002144 (ADT) $R^2 = 0.54$

The relationships are much stronger for undivided bridges than divided bridges.

For undivided bridges, the effect of traffic volume is also fairly strong, as shown in Table A.143. The percentage of same direction conflicts increases with higher ADT while that of opposite direction and angle conflicts decreases. Similar trends are present for divided bridges, but are too weak to be of much significance. However, there are no apparent trends to indicate that traffic volume has any effect on the distribution of object struck, as shown in Table A.144.

5.6 Summary

The development of a SAMPLE file and descriptive statistics concerning the file are discussed in this chapter. The file contains

TABLE 52

DISTRIBUTION OF FIRST HARMFUL EVENT BY AVERAGE DAILY TRAFFIC

	First Harmful Event									
	Another Vehicle		Fixed Object		Overturned		Other		Total	
Average Daily Traffic	No.	%	No.	%	No.	%	No.	%	No.	%
UNDIVIDED BRIDGES										
1-399	7	19.4	16	44.4	5	13.9	8	22.2	36	0.5
400-999	112	29.0	185	48.1	39	10.2	49	12.8	385	5.5
1,000-1,999	278	27.9	431	43.4	126	12.7	159	16.0	994	14.1
2,000-2,999	446	42.7	398	38.1	86	8.2	113	10.8	1,043	14.8
3,000-3,999	378	36.5	384	37.1	100	9.6	170	16.5	1,032	14.6
4,000-4,999	388	40.3	401	41.6	56	5.9	114	11.9	960	13.6
5,000-7,999	650	48.3	450	33.4	77	5.8	169	12.5	1,346	19.1
8,000-11,999	311	55.6	195	34.8	11	1.9	43	7.7	559	7.9
12,000-15,999	327	60.6	117	21.8	15	2.9	80	14.8	539	7.6
≥ 16,000	105	68.2	23	14.9	3	1.9	23	14.9	154	2.2
Total	3,001	42.6	2,600	36.9	519	7.4	929	13.2	7,048	100.0
DIVIDED BRIDGES										
1,000-1,999	17	41.0	15	37.3	3	8.3	6	13.4	41	0.7
2,000-2,999	15	15.1	54	53.0	16	16.0	16	16.0	102	1.8
3,000-3,999	27	17.0	87	54.0	31	19.3	15	9.7	160	2.9
4,000-4,999	31	18.3	90	52.9	26	15.1	23	13.7	171	3.0
5,000-7,999	225	32.5	308	44.5	57	8.2	103	14.8	693	12.4
8,000-11,999	401	33.3	581	48.2	84	7.0	138	11.5	1,204	21.5
12,000-15,999	287	34.5	447	53.6	70	8.4	29	3.5	832	14.8
16,000-19,999	235	38.7	285	46.9	45	7.3	43	7.1	608	10.8
20,000-24,999	219	41.1	244	45.8	34	6.4	36	6.7	533	9.5
25,000-34,999	204	50.3	154	38.0	23	5.6	25	6.2	507	7.3
35,000-49,999	170	47.3	150	41.7	22	6.2	17	4.8	359	6.4
≥ 50,000	377	75.4	104	20.8	5	1.0	14	2.8	500	8.9
Total	2,209	39.4	2,520	44.9	417	7.4	465	8.3	5,611	100.0

weighted data for 1,088 two-lane divided bridges and 6,574 two-lane undivided structures. While the file is not completely representative of the POPULATION bridges, the error is not significant--probably less than 10 percent.

Notable highlights from descriptive statistics of the SAMPLE file follow:

- An average two-lane undivided structure is 169 feet long, 27.7 feet wide with 11-foot lanes and approach roadway width of 29.8 feet. About half have approach guardrails. For two-lane divided structures, the average bridge width is 245 feet long, 36.8 feet with 12-foot lanes and approach roadway width of 40 feet. Guardrails exist on almost all of the approaches to the bridges.

- ADT on undivided bridges is usually less than 1,000 vehicles per day. The majority of divided structures have ADT of more than 8,000 vehicles per day.

- Most bridges are straight and level, indicating the older practice of making grade changes on the approaches.

- As bridge length increases, the bridge width, the percentage of bridges with shoulder reduction and the extent of the shoulder reduction increase. For undivided narrow bridges ($\leq$ 24 feet), most have no approach shoulders or large shoulder reductions. For divided structures with bridge widths above 36 feet, the percentage with no shoulder reduction increases drastically.

- The general trend for all bridges is for the Bridge Safety Index (BSI) to increase for wider bridge widths. However, the index is not significantly affected by the presence/absence of approach shoulder or shoulder reduction.

- Approach shoulder widths for undivided bridges with no shoulder reduction are much smaller than those for bridges with shoulder reduction. Since shoulder reduction is primarily a function of approach shoulder width, it may not be an appropriate indicator for bridge narrowness.

- Bridges with accidents have much higher ADT, greater bridge length (especially for bridges with shoulder reduction or no approach shoulder), and for undivided bridges, greater degree of curvature and shorter tangent distance than bridges with no accidents. However, bridge roadway widths are similar for bridges with or without accidents.

- Accident frequencies are much higher on urban bridges than on rural bridges and decrease with lower highway types (highest for interstate to lowest for collector roadway). Accident rates are only slightly higher on urban bridges and increase with lower highway types except for collector roadways. Accident severities are higher in rural areas than in urban areas, reflecting higher operating speeds and greater percentage of single vehicle accidents in rural areas.

- The percentage of divided bridges with accidents is more than three times that of undivided bridges with much higher accident frequency. However, there is very little difference in accident rate, indicating the effect of higher traffic volumes on divided bridges. When only bridges with accidents are compared, the frequency is only slightly higher and the rate much lower for divided bridges. This reflects the higher percentage of accident bridges for the divided structure.

- The percentage of bridges with accidents increases with greater shoulder reduction and bridge widths.

- Accident frequencies increase with greater values of bridge length, bridge width, percent shoulder reduction, degree of curvature on the bridge and approaches, percent grade on the bridge and ADT.

- Accident rates also increase with greater values of bridge length, percent shoulder reduction, degree of curvature on the bridge and approaches, and percent grade on the bridge, but are unaffected by bridge width. A weak relationship between accident rate and ADT suggests that the rate increases with higher ADT for undivided bridges but decreases for divided bridges.

- Accident frequencies and rates increase drastically with increasing degree of roadside distraction. Contrary to expectation, a strong trend also exists for higher frequencies and rates for bridges with warning and/or no passing signs, longitudinal marking, and delineator/object markers. The cause might be that such traffic control devices are installed at bridges with higher traffic volumes and/or with past accident experience.

- Accident frequencies and rates generally decrease with increasing Bridge Safety Index (BSI), but the relationships are weak, especially for undivided bridges.

- The average severity of accidents on divided bridges is slightly less than that on undivided bridges. Accident severity increases with greater values of bridge length, percent shoulder reduction, speed limit and BSI rating, but decreases with greater bridge width, higher level of roadside distraction and increasing ADT. However, the relationships are generally very weak except for roadside distraction.

- Fixed object impacts have the highest severity for undivided bridges, followed by rollovers and collisions with another vehicle. For divided bridges, rollovers are the most severe, followed by fixed object impacts and collisions with another vehicle. Bridge end/abutment impacts result in the highest severity in terms of object struck while opposite direction conflicts are the most severe and same direction conflicts are the least severe for vehicle-to-vehicle collisions.

- More collisions with another vehicle and less fixed object impacts occur on undivided bridges than on divided bridges. The percentage of collisions with another vehicle decreases and the percentage of fixed object impacts and rollovers increases with greater bridge width, less shoulder reduction, greater degree of curvature, level grade, reduced level of roadside distraction, presence of signing, delineator/object marker, and approach guardrail but no longitudinal marking, and, most importantly, lower ADT.

- The percentage of guardrail/median barrier impacts is lower and other fixed object impacts higher for undivided bridges than for divided bridges. This reflects the more extensive use of approach guardrail and median barrier and the lesser clutter of fixed objects with divided structures. The percentages of impacts with bridge rail and bridge end/abutment are slightly lower for undivided bridges. Also, the percentage of opposite direction conflicts seems to decrease with greater bridge width.

CHAPTER VI. RELATIONSHIPS BETWEEN BRIDGE CHARACTERISTICS AND ACCIDENTS

6.1 Introduction

A principal objective of this study was to determine the relationships between the frequency and severity of motor vehicle accidents at bridges and their approaches to bridge structural and design characteristics and to the geometrics and conditions of their approaches. Data from the SAMPLE file were used for the analyses which were entirely statistical in nature. Descriptive statistics on the SAMPLE file have been previously presented in Chapter V. This chapter will highlight the results of the statistical analyses and identified relationships.

6.1.1 Statistical Analyses

Extensive statistical analyses were conducted on the SAMPLE file to determine the relationships. Various statistical techniques were used, including analysis of variance, correlation analysis, factor analysis, single and multiple linear regression, and discriminant analysis. Analysis of the data using the categorical analysis technique was also attempted, but found to be unreliable because of the large number of empty cells. Brief descriptions of these statistical techniques are provided in Appendix E. For those interested in greater details on these statistical techniques, there are many reference and text books available.

During the course of the analysis, various stratification schemes were used to categorize the data, including:

1. Undivided vs. divided bridges
2. Bridge width $\leq$ 24 ft. vs. bridge width > 24 ft. (undivided bridges only)
3. Narrow (i.e., with shoulder reduction or $\leq$ 24 ft. for divided bridges) vs. non-narrow (i.e., no shoulder reduction or no approach shoulder)
4. Urban vs. rural bridges
5. Hazardous (i.e., bridges with accidents) vs. non-hazardous (i.e., bridges with no accidents) bridges
6. Bridges with no (K + A) injuries vs. bridges with (K + A) injuries.

These stratification variables may be used singly or in combination depending on the analysis being conducted.

With the large number of data items available from the SAMPLE file, the first task in the analysis was to narrow down the number of variables to a manageable size. Table 53 shows the list of variables that were selected for analyses and the corresponding codes. The list of variables was further reduced after some preliminary analyses, details of which are described in the later subsections.

Most of the analysis results are contained in Appendix M while only highlights of the more significant relationships are presented herein. It should be noted that all analyses were conducted using a weighted file to reflect the bridge population as defined in the POPULATION file.

6.1.2 Independent Variables

The list of independent variables includes 31 variables on bridge, approach, operational, and countermeasure characteristics that are considered to be the most significant features at bridge sites, all of which are either available from existing State data files or readily obtainable from inspection of the bridge. There are an additional nine variables pertaining to the Bridge Safety Index. The concept of a simple index to reflect the relative hazard or safety between different bridges is very appealing from an operational standpoint. An attempt was thus made to evaluate how well the BSI is related to accident frequency and/or severity at bridge sites.

Preliminary analyses were conducted to further screen and reduce the number of independent variables. Correlation and factor analyses were used to identify pairs or groups of variables that are highly correlated with each other. Then, for each pair or group of variables that are highly correlated, the most prominent variable was selected for further analysis and the remaining variable(s) was eliminated from the lists of independent variables. The only exceptions are bridge roadway width, percent shoulder reduction, and percent roadway width reduction which are very highly correlated. In order to assess the effect of shoulder reduction on accident frequency and severity while keeping bridge roadway width as a key bridge characteristic, both variables are included as independent variables for analysis.

Results from simple linear regression analysis were also used in the screening process. Variables that are shown to have no relationship with accident frequency and severity are eliminated from further evaluation to keep the number of independent variables to a manageable size.

Furthermore, many of the BSI factors are highly correlated with their counterparts on bridge, approach, and operational characteristics,

TABLE 53

LIST OF VARIABLES AND CORRESPONDING CODES

Variable	Codes
BRIDGE CHARACTERISTICS	
1. Bridge Length	Actual Value in Feet
2. Bridge Roadway Width (Including Shoulders)	Actual Value in Feet
3.* Aspect Ratio $\left(\frac{\text{Bridge Width}}{\text{Bridge Length}}\right)$	Actual Value
4.* Bridge Lane Width	Actual Value in 0.1 Foot
5. Bridge Curb Presence	(0) No Curb (1) Curb
6. Degree of Curvature - Bridge	(0) Straight (0.1)-(99.8) Actual Value in 0.1 Degree
7. Maximum Vertical Grade - Bridge	(0) Level Undivided: (0.1)-(9.9) Actual Value in 0.1 Percent Divided: (-9.9)-(+9.9) Actual Value in 0.1 Percent
8.* Bridge Deck Condition	(0)-(8) Rating from Beyond Repair to Good Condition
9.* Bridge Structural Appraisal	(0)-(8) Rating from Bridge Closed Requiring Replacement to New Bridge
10.* Bridge Deck Geometry Appraisal	(0)-(8) Rating from Requiring Replacement to Good Condition

---

* Note. The asterisk denotes that the variable was eliminated from further evaluation after the preliminary analyses.

TABLE 53 (Cont'd)

Variable	Codes
APPROACH CHARACTERISTICS	
1. Maximum Degree of Curvature - Approach	(0) Straight (0.1)-(99.8) Actual Value in 0.1 Degree
2.* Tangent Distance	(0)-(996) Actual Value in Feet (997) 997 Feet or More (998) N/A - No Curve
3. Sight Distance	(0)-(996) Actual Value in Feet (997) 997 Feet or More
4. Maximum Vertical Grade - Approach	(0) Level Undivided: (0.1)-(9.9) Actual Value in 0.1 Percent Divided: (-9.9)-(+9.9) Actual Value in 0.1 Percent
5. Percent Shoulder Reduction	(0) No Shoulder Reduction or No Approach Shoulder (1)-(100) Actual Value in Percent
6.* Percent Lane Width Reduction	(0) No Lane Width Reduction (1)-(100) Actual Value in Percent
7.* Percent Roadway Width Reduction	(0) No Roadway Width Reduction (1)-(100) Actual Value in Percent
8.* Speed Limit Reduction	(0) No Speed Limit Reduction Actual Value in MPH
OPERATIONAL CHARACTERISTICS	
1. Urban/Rural	(1) Urban (2) Rural
2. Speed Limit	Actual Value in MPH
3. Average Daily Traffic	Actual Value
4. Percent Truck	Actual Value in 0.1 Percent

TABLE 53 (Cont'd)

Variable	Codes
5. Roadside Distraction	(0) None (1) Few (2) Moderate (3) Heavy (4) Continuous
COUNTERMEASURE INFORMATION	
1. Signing	(0) None (1) Yes
2. Roadway Longitudinal Marking	(0) None (1) Center/Lane or Edge Lines Only (2) Center/Lane and Edge Lines
3. Delineator/Object Marker Presence	(0) None (1) Yes
4.* Bridge Rail Rating	(0) Not Meeting Standards (1) Meeting Standards
5.* Approach Guardrail Rating	(0) Not Meeting Standards (1) Meeting Standards
6.* Guardrail to Bridge Rail Transition Rating	(0) Not Meeting Standards (1) Meeting Standards
7.* Guardrail End Treatment Rating	(0) Not Meeting Standards (1) Meeting Standards
8. Barrier Rating (Composite of Bridge Rail, Approach Guardrail, Transition, and End Treatment Ratings)	(0)-(20) Rating from No Barrier Present to All Barriers Conforming to Standards
BRIDGE SAFETY INDEX (BSI)†	
1. BSI Factor 1 - Bridge Width	(0)-(20) Actual Value
2. BSI Factor 2 - Lane Width	(0)-(20) Actual Value
3.* BSI Factor 3 - Barrier Rating	(0)-(20) Actual Value
4. BSI Factor 4- Sight Distance	(1)-(5) Actual Value
BSI Factor 5 - Tangent Distance	(1)-(5) Actual Value
6. BSI Factor 6 - Grade Continuity	(1)-(5) Actual Value
7. BSI Factor 7 - Shoulder Reduction	(1)-(5) Actual Value

TABLE 53 (Cont'd)

Variable	Codes
8. BSI Factor 10 - Roadside Distraction	(1)-(5) Actual Value
9. Total BSI (Sum of BSI Factors 1-7 and 10 converted to a basis of 100)	(1)-(100) Actual Value

† Note. See Table 3 on the assignment of factor ratings. BSI factors 8 and 9 cannot be determined from available data.

ACCIDENT FREQUENCY MEASURES

1. Number of Accidents Per Year Per Bridge	Actual Value
2. Number of Accidents Per Million Vehicles	Actual Value
3.* Number of Accidents Per Year Per Mile of Bridge and Approach	Actual Value
4.* Number of Accidents Per 10^8 Vehicle Miles of Travel on Bridge and Approach	Actual Value

ACCIDENT SEVERITY MEASURES

1. Average Accident Cost Per Accident	Actual Value in $
2. Percent (K + A) Injury Accidents	Actual Value in Percent

ACCIDENT COST MEASURES

1. Accident Cost Per Year Per Bridge	Actual Value in $
2. Accident Cost Per Million Vehicles	Actual Value in $
3.* Accident Cost Per Year Per Mile of Bridge and Approach	Actual Value in $
4.* Accident Cost Per 10^8 Vehicle Miles of Travel on Bridge and Approach	Actual Value in $

as expected. In order to assess the relationship of the BSI factors on accident frequency and severity while maintaining independency between the variables, two separate sets of independent variables are used in the analyses, one consisting of bridge, approach, operational, and countermeasure characteristics while the second contains only BSI factors and related variables, as shown in Table 54.

Results from the analyses indicate that the relationships between BSI factors and accident frequency and severity are indeed similar to their counterparts on bridge, approach, and operational characteristics, but somewhat weaker. Thus, the results of the analyses using BSI factors as independent variables are not included in this report.

As shown in Table A.145, the screening process has eliminated most of the high correlations among the independent variables with the exception of between bridge width and percent shoulder reduction for divided bridges ($r = -0.89$). Otherwise, the correlation coefficients are all under 0.60, which indicates that reasonable independence exists between the variables.

Results from the factor analysis, as shown in Table A.146, reflect similar relationships between the independent variables as from the correlation analysis. Six factors are identified for undivided bridges. Factor I characterizes the horizontal alignment of approaches to the bridge, accounting for 31.4 percent of the sample variation. Factor II, explaining 28 percent of the sample variation, is associated with average daily traffic, urban/rural and roadside distraction. Curb presence, longitudinal marking and delineator/object marker presence form the third factor with 12.7 percent of the sample variation. The fourth factor reflects the association between bridge width and the bridge safety index. Vertical alignment on the bridge and its approaches is characterized in Factor V while the last factor shows the association between roadway width and percent shoulder reduction.

For divided bridges, six factors are also chosen that are somewhat different from those of undivided bridges. Factor I characterizes bridge width, percent shoulder reduction and curb presence with 39.8 percent of the sample variation. The second factor describes the general operational characteristics of the bridge, including curb presence, sight distance, roadside distraction, percent truck, and barrier rating. Vertical alignment of the bridge and its approaches is contained in Factor III while the relationship between average daily traffic and urban/rural is manifested

TABLE 54

LIST OF INDEPENDENT VARIABLES

BRIDGE, APPROACH, OPERATION AND COUNTERMEASURE CHARACTERISTICS

1. Bridge Length
2. Bridge Roadway Width
3. Bridge Curb Presence
4. Degree of Curvature - Bridge
5. Maximum Vertical Grade - Bridge
6. Degree of Curvature - Approach
7. Sight Distance
8. Maximum Vertical Grade - Approach
9. Speed Limit
10. Roadside Distraction
11. Signing
12. Roadway Longitudinal marking
13. Delineator/Object Marker Presence
14. Bridge Safety Index (BSI)
15. Percent Shoulder Reduction
16. Urban/Rural
17. Average Daily Traffic
18. Percent Truck
19. Barrier Rating

BRIDGE SAFETY INDEX FACTORS

1. BSI Factor 1 - Bridge Width
2. BSI Factor 2 - Lane Width
3. Barrier Rating (BSI Factor 3)
4. BSI Factor 4 - Target Distance
5. BSI Factor 5 - Sight Distance
6. BSI Factor 6 - Grade Continuity
7. BSI Factor 7 - Shoulder Reduction
8. BSI Factor 10 - Roadside Distraction
9. Total BSI

10.* Average Daily Traffic

11.* Percent Truck

* Note: The inclusion of average daily traffic and percent truck is intended as proxy measures for BSI factors 8 and 9, respectively.

in Factor IV. Horizontal alignment of the bridge and its approaches is depicted in Factor V. The last factor shows the association between bridge safety index, longitudinal marking, and speed limit.

Tables A.147 and A.148 illustrate the factor matrices for narrow and non-narrow categories of undivided and divided bridges. The factors are basically the same between narrow, non-narrow, and all bridges for both undivided and divided bridges except for percent shoulder reduction, which does not apply to non-narrow bridges. The order of the factors and percent variation explained do vary between narrow, non-narrow, and all bridges. This indicates that the relationships among the independent variables are essentially unaffected by the narrow and non-narrow categorization although the strength of the correlations does vary.

Table 55 summarizes the average values of the independent variables for narrow versus non-narrow bridges and the percent difference between them. For undivided bridges 24 feet or less in width, narrow bridges are associated with higher degree of curvature on both the bridge and its approaches, greater level of roadside distraction, higher traffic volume, more signing, and better barrier rating than non-narrow bridges. For undivided bridges wider than 24 feet, narrow bridges are still associated with higher traffic volume and more signing, but the percent difference for the other factors is much smaller. A new addition is bridge length which is much greater for narrow bridges.

Overall, narrow undivided bridges have longer bridge length, greater degree of curvature on the bridge, more signing and higher traffic volume. Narrow divided bridges are also associated with the same characteristics plus greater percentage of curb presence, steeper downgrade on the bridge and upgrade in the approaches, higher degree of roadside distraction, and lower barrier rating.

6.1.3 Dependent Variables

Ten dependent variables were selected initially, four on accident frequency and rate, two on accident severity, and the remaining four on accident cost measures. Definitions and discussions on the four accident fequency measures have been presented in Chapter II. The basic accident frequency measure is number of accidents per year per bridge which is then adjusted for the average daily traffic to obtain the accident rate of number of accidents per million vehicles. Adjustments for the length of the bridge

TABLE 55

AVERAGE VALUES OF INDEPENDENT VARIABLES FOR NARROW VERSUS NON-NARROW BRIDGES

	Undivided Bridges									Divided Bridges		
	≤ 24'			> 24'			Total					
Variable	Narrow	Non-Narrow	% Difference*	Narrow	Non-Narrow	% Difference	Narrow	Non-Narrow	% Difference	Narrow	Non-Narrow	% Difference
Bridge Le	152.8	143.1	6.7	237.4	153.7	54.5	196.7	148.7	32.3	308.1	202.5	52.1
Bridge Width	22.1	22.2	-0.5	31.2	34.3	-9.0	26.8	28.6	-6.3	32.2	40.3	-20.1
Curb Presence	0.434	0.353	22.9	0.683	0.555	23.1	0.563	0.460	22.4	0.804	0.520	54.6
° Curvature - Bridge	0.228	0.031	635.5**	0.278	0.239	16.3	0.254	0.142	78.9	0.337	0.244	38.1
% Grade - Bridge	0.845	0.941	-10.2	0.903	0.889	1.6	0.875	0.914	-4.3	-0.185	0.066	-380.3
° Curvature - Approach	2.755	1.996	38.0	1.661	1.803	-7.9	2.188	1.894	15.5	1.026	0.583	76.0
Sight Distance	843.6	865.3	-2.5	905.3	867.9	4.3	875.5	866.6	1.0	946.5	963.1	-1.7
% Grade - Approach	2.401	2.748	-12.6	1.920	2.025	-5.2	2.151	2.365	-9.0	0.223	0.174	28.2
Speed Limit	51.5	53.0	-2.8	53.0	53.3	-0.6	52.23	53.17	-1.8	54.43	54.64	-0.4
Roadside Distraction	1.33	1.057	25.8	1.615	1.512	6.8	1.478	1.298	13.9	2.183	1.738	25.6
Signing	0.395	0.235	68.1	0.199	0.117	70.1	0.293	0.173	69.4	0.079	0.040	97.5
Marking	1.105	0.984	12.3	1.470	1.465	0.3	1.294	1.239	4.4	1.891	1.959	-3.5
Delineator	0.751	0.717	4.7	0.592	0.501	18.2	0.668	0.602	11.0	0.669	0.776	-13.8
Bridge Safety Index	60.96	65.24	-6.6	75.82	76.23	-0.5	68.66	71.06	-3.4	77.32	79.68	-3.0
% Shoulder Reduction	76.99			56.44			66.33			49.44		
Urban/Rural	1.979	1.991	-0.6	1.947	1.959	-0.6	1.962	1.974	-0.6	1.569	1.772	-11.5
ADT	1031.9	528.7	95.2	2499.1	1979.6	26.2	1792.6	1279.4	40.1	14135.1	9104.1	55.3
% Truck	12.23	12.39	-1.3	10.80	10.06	7.4	11.48	11.16	2.9	12.30	15.21	-19.1
Barrier Rating	3.728	2.803	33.0	7.559	6.719	12.5	5.714	4.878	17.1	10.52	14.27	-26.3
Sample Size	1,534	1,414		1,652	1,594		3,187	3,008		459	541	

* Note. $\% \text{ Difference} = \dfrac{(\text{Variable}_{\text{Narrow}}) - (\text{Variable}_{\text{Non-Narrow}})}{(\text{Variable}_{\text{Non-Narrow}})} \times 100\%$

e.g., For bridge length of undivided bridges, ≤ 24'

$$\% \text{ Difference} = \frac{152.8 - 143.1}{143.1} \times 100\% = 6.7\%$$

** Percent difference of 25% or greater is underlined for added emphasis.

and its approaches produce another accident rate of number of accidents per year per mile of bridge and approach. The fourth accident rate of number of accidents per 100 million vehicle miles of travel-bridge and approach is obtained by adjusting for both the average daily traffic and the length of the bridge and its approaches.

The severity measure of average accident cost per accident is obtained by converting the highest occupant injury severity, expressed in terms of Police Injury Codes (PIC), to accident costs, using accident cost figures from the National Safety Council as previously explained in Chapter V. The other severity measure of percent (K + A) injuries is obtained by dividing the number of accidents with K (fatal) or A (incapacitating) injuries by the total number of accidents for each bridge.

The four accident cost measures are simply products of the average accident cost per accident with each of the four accident frequency or rate measures. The accident cost measures allow evaluation of both accident frequency or rate and severity of the bridges simultaneously using a single variable expressed in accident costs.

The correlation matrices for these dependent variables, shown in Tables A.149 and A.150, indicate that high degrees of correlation exist between these variables. Adjustment for the length and its approaches appears to have little impact with nearly perfect correlation between accidents per year per bridge and accidents per year per mile of bridge and approach and between accidents per million vehicles to accidents per 100 million vehicle-miles of travel on bridges and approaches. Also, accident cost measures are highly correlated with their accident frequency or rate counterparts. The two severity measures are somewhat correlated as are accident cost per accident to the accident cost measures.

It was then decided that there is no need to adjust for the length of the bridge at its approaches, thus eliminating the four measures of per year per mile and per 100 million vehicle-miles of travel. Accident costs per accident appears to be a better indicator of accident severity than percent (K + A) injuries and is used in all analyses except for discriminant analysis, in which bridges with no (K + A) injury accidents are compared to those with such accidents. The list of dependent variables is then reduced to:

Accident Frequency or Rate Measures
- Number of Accidents Per Year Per Bridge
- Number of Accidents Per Million Vehicles

Accident Severity Measure
    Average Accident Cost Per Accident
Accident Cost Measures
    Accident Cost Per Year Per Bridge
    Accident Cost Per Million Vehicles

6.2 Relationships for Individual Factors

Analysis of variance (ANOVA) and simple regression runs were made on individual independent and dependent variables to identify their relationships and significance, if any. The results are shown in Table 56 for undivided bridges and in Table 57 for divided bridges. For each combination of dependent and independent variables, the F ratio and its level of significance (Pr > F), the regression coefficient of determination (R^2), the intercept (b_o) and the slope (b_1) of the regression line are provided in the tables. Note also that the ANOVA significance level (Pr > F) of ≤ 0.01 and the regression coefficient of determination (R^2) values of ≥ 0.02 are underlined for emphasis.

Overall, the relationships between accident frequency and severity and individual bridge, approach, operational, and countermeasure characteristics and the bridge safety index factors are similar to those previously discussed under Section 5.4 of Chapter V. However, the relationships are rather weak except for average daily traffic. The R^2 values are too low in most cases for the purpose of any meaningful predictions for accident frequency/rate or severity. Nevertheless, the trends are present as indicated by the F ratios and their levels of significance. The generally low R^2 values indicate that only small percentages of sample variation can be explained by the regression models for individual features. This is not surprising when the high level of variability in the data is taken into consideration. The standard deviations are very large in relation to the means, particularly in light of the large sample size. Furthermore, the accident frequencies and rates are not normally distributed, but resemble that of Poisson distribution.

More detailed discussions on individual features will be presented in the following subsections. Relationships between two variables may be termed as positive or negative. A positive correlation means that the value of one variable tends to increase as the value of the other variable increases while a negative correlation indicates that the value of one variable tends to increase as the value of the other variable decreases.

TABLE 56

SUMMARY OF REGRESSION AND ANOVA RESULTS FOR UNDIVIDED BRIDGES

Variable	Item	Accident/ Year/Bridge	Accident/ 10^6 Vehicles	Accident Cost/ Accident	Accident Cost/ Year/Bridge	Accident Cost/ 10^6 Vehicles
		BRIDGE CHARACTERISTICS				
Bridge Length	F (Pr > F)	**31.66(0.0001)***	**15.97(0.0001)**	**10.07(0.002)**	**18.90(0.001)**	**7.35(0.007)**
	R^2	**0.022**	0.011	0.007	0.013	0.005
	b_o	0.215	0.2819	882.90	1242.7	1641.7
	b_1	0.000846	0.0007	2.870	6.086	6.270
Bridge Roadway Width	F (Pr > F)	**10.24(0.001)**	0.23(0.628)	3.64(0.057)	1.79(0.181)	0.01(0.934)
	R^2	0.007	0.0002	0.003	0.001	0.00001
	b_o	0.006	0.3405	113.21	905.15	2849.2
	b_1	0.01274	0.0023	45.43	49.52	-5.045
Bridge Lane Width	F (Pr > F)	1.42(0.234)	0.00(0.964)	1.21(0.272)	0.75(0.386)	0.01(0.907)
	R^2	0.001	0.000001	0.0009	0.0005	0.00001
	b_o	0.142	0.3936	178.30	815.15	2385.6
	b_1	0.01938	0.0009	106.75	130.79	29.01
Curb Presence	F (Pr > F)	**25.22(0.0001)**	**12.84(0.0004)**	5.15(0.024)	**8.13(0.005)**	1.17(0.279)
	R^2	**0.035**	0.018	0.007	0.12	0.002
	b_o	--	--	--	--	--
	b_1	--	--	--	--	--
Degree of Curvature - Bridge	F (Pr > F)	**36.08(0.0001)**	**78.33(0.0001)**	3.35(0.068)	**14.90(0.0001)**	6.13(0.013)
	R^2	**0.025**	**0.052**	0.002	0.010	0.004
	b_o	0.3267	0.3492	1311.6	2084.6	2507.2
	b_1	0.1567	0.2662	288.11	940.56	995.9
Maximum Vertical Grade - Bridge	F (Pr > F)	6.28(0.012)	4.67(0.031)	0.28(0.594)	**6.93(0.009)**	1.29(0.257)
	R^2	0.004	0.003	0.0002	0.005	0.0009
	b_o	0.3045	0.3487	1301.3	1750.4	2336.2
	b_1	0.0608	0.0614	77.56	592.8	420.9
		APPROACH CHARACTERISTICS				
Degree of Curvature - Approach	F (Pr > F)	**26.29(0.0001)**	**36.90(0.0001)**	1.63(0.202)	**11.08(0.0009)**	3.36(0.067)
	R^2	0.018	**0.025**	0.001	0.008	0.002
	b_o	0.2894	0.3078	1267.2	1857.8	2330.6
	b_1	0.0323	0.0446	48.43	195.29	177.3
Tangent Distance	F (Pr > F)	5.77(0.017)	6.04(0.014)	0.05(0.823)	0.07(0.793)	0.42(0.516)
	R^2	0.008	0.008	0.00007	0.00009	0.0006
	b_o	0.5921	0.6992	1520.97	3107.4	3983.5
	b_1	-0.0008	-0.0010	0.3506	-0.7754	-3.103
Sight Distance	F (Pr > F)	**16.10(0.0001)**	**19.96(0.0001)**	0.01(0.910)	1.99(0.159)	1.14(0.285)
	R^2	0.011	0.014	0.00001	0.001	0.0008
	b_o	0.8468	1.0384	1287.8	3876.0	4706.1
	b_1	-0.0006	-0.0007	0.0950	-1.848	-2.306

* Note. ANOVA significance level (Pr > F) of ≤ 0.01 and the regression coefficient of determination (R^2) values of ≥ 0.02 are underlined for emphasis.

TABLE 56 (Cont'd)

Variable	Item	Accident/ Year/Bridge	Accident/ 10^6 Vehicles	Accident Cost/ Accident	Accident Cost/ Year/Bridge	Accident Cost/ 10^6 Vehicles
Maximum Vertical Grade - Approach	F (Pr > F)	0.04(0.846)	0.00(0.992)	0.42(0.517)	0.050(0.824)	0.02(0.887)
	R^2	0.00003	0.0000	0.0003	0.00004	0.00001
	b_o	0.3649	0.4027	1499.8	2205.6	2635.8
	b_1	-0.0029	0.0002	-57.80	30.87	32.47
Percent Shoulder Reduction	F (Pr > F)	20.99(0.0001)	15.05(0.0001)	10.72(0.001)	18.10(0.0001)	8.09(0.005)
	R^2	0.015	0.011	0.008	0.013	0.006
	b_o	0.2449	0.2905	884.1	1297.2	1629.6
	b_1	0.003366	0.003340	14.42	29.01	32.02
Percent Lane Width Reduction	F (Pr > F)	3.53(0.060)	4.99(0.026)	0.19(0.664)	0.49(0.484)	0.09(0.759)
	R^2	0.002	0.004	0.0001	0.0003	0.00007
	b_o	0.3361	0.3721	1401.3	2198.2	2653.8
	b_1	0.01085	0.01508	-15.00	37.56	27.03
Percent Roadway Width Reduction	F (Pr > F)	60.16(0.0001)	32.72(0.0001)	21.62(0.0001)	36.01(0.0001)	11.28(0.001)
	R^2	0.041	0.023	0.015	0.025	0.008
	b_o	0.1873	0.2541	749.3	1037.1	1559.3
	b_1	0.01640	0.01428	59.50	118.6	110.2
Speed Limit Reduction	F (Pr > F)	27.34(0.001)	4.31(0.038)	0.02(0.888)	1.57(0.211)	0.01(0.910)
	R^2	0.019	0.003	0.00001	0.001	0.00001
	b_o	0.3362	0.3928	1367.0	2226.1	2702.6
	b_1	0.06693	0.03134	10.85	149.8	22.25
		OPERATIONAL CHARACTERISTICS				
Speed Limit	F (Pr > F)	46.28(0.0001)	60.73(0.0001)	0.23(0.635)	3.60(0.058)	1.85(0.174)
	R^2	0.032	0.041	0.0002	0.003	0.001
	b_o	2.0757	2.693	2098.8	6783.3	8029.5
	b_1	-0.0327	-0.0436	-13.87	-85.83	-101.3
Average Daily Traffic	F (Pr > F)	700.6(0.0001)	33.79(0.0001)	78.62(0.0001)	177.48(0.0001)	6.77(0.009)
	R^2	0.331	0.023	0.0526	0.111	0.005
	b_o	-0.0739	0.2689	340.82	-50.47	1918.0
	b_1	0.0002	0.00009	0.6747	1.525	0.5184
Percent Truck	F (Pr > F)	29.00(0.0001)	13.51(0.0002)	1.85(0.174)	2.56(0.110)	0.59(0.443)
	R^2	0.021	0.010	0.0013	0.002	0.0004
	b_o	0.6179	0.6130	1798.8	3049.3	3347.2
	b_1	-0.0224	-0.0179	-34.16	-62.42	-49.37
Roadside Distraction	F (Pr > F)	218.88(0.0001)	81.15(0.0001)	28.35(0.0001)	56.19(0.0001)	9.00(0.003)
	R^2	0.134	0.054	0.020	0.038	0.006
	b_o	-0.233	-0.0375	17.0	-653.7	747.2
	b_1	0.4246	0.3161	970.9	2102.6	1407.6

TABLE 56 (Cont'd)

Variable	Item	Accident/ Year/Bridge	Accident 10^6 Vehicles	Accident Cost/ Accident	Accident Cost/ Year/Bridge	Accident Cost/ 10^6 Vehicles
		BRIDGE SAFETY INDEX FACTOR				
BSI Factor 1 - Clear Bridge Width	F (Pr > F)	15.58(0.0001)	3.36(0.0668)	7.53(0.006)	6.27(0.012)	0.57(0.449)
	R^2	0.011	0.002	0.005	0.004	0.0004
	b_o	-0.4422	-0.03398	-1961.9	-2448.7	352.6
	b_1	0.04388	0.02395	182.6	258.9	129.1
BSI Factor 2 - Lane Width	F (Pr > F)	11.82(0.0006)	9.35(0.002)	1.80(0.180)	4.93(0.027)	0.55(0.458)
	R^2	0.008	0.007	0.001	0.003	0.0004
	b_o	0.5894	0.6436	1910.4	3662.9	3474.3
	b_1	-0.02241	-0.02333	-52.39	-134.6	-74.20
BSI Factor 3 - Barrier Rating	F (Pr > F)	35.09(0.0001)	16.75(0.0001)	19.07(0.001)	18.42(0.0001)	6.31(0.012)
	R^2	0.024	0.012	0.013	0.013	0.004
	b_o	0.04253	0.1469	-25.37	146.5	656.4
	b_1	0.03013	0.02454	133.7	204.0	197.4
BSI Factor 3 - Barrier Rating (Revised)	F (Pr > F)	2.92(0.088)	0.02(0.890)	3.06(0.804)	2.59(0.108)	0.08(0.775)
	R^2	0.002	0.00002	0.002	0.002	0.0001
	b_o	0.2995	0.3868	1089.5	1865.6	2576.7
	b_1	0.007028	0.0006821	44.2	62.91	18.1
BSI Factor 4 - Sight Distance	F (Pr > F)	5.94(0.015)	3.20(0.074)	0.00(0.956)	2.26(0.133)	0.31(0.578)
	R^2	0.004	0.002	0.000002	0.002	0.0002
	b_o	0.7567	0.7454	1424.3	4555.6	4101.4
	b_1	-0.08477	-0.07283	-11.57	-485.3	-296.2
BSI Factor 5 - Tangent Distance	F (Pr > F)	19.94(0.0001)	27.91(0.0001)	0.78(0.378)	5.68(0.017)	4.08(0.044)
	R^2	0.014	0.019	0.0006	0.004	0.003
	b_o	0.6731	0.8373	1744.6	3841.3	4893.6
	b_1	-0.08177	-0.1128	-97.11	-406.9	-567.6
BSI Factor 6 - Grade Continuity	F (Pr > F)	0.27(0.606)	0.16(0.689)	0.74(0.391)	0.13(0.720)	0.06(0.812)
	R^2	0.0002	0.0001	0.0005	0.0001	0.00004
	b_o	0.2599	0.4922	392.7	1642.0	2015.4
	b_1	0.02075	-0.01879	206.0	133.4	146.1
BSI Factor 7 - Shoulder Reduction	F (Pr > F)	18.87(0.001)	14.54(0.0001)	10.86(0.001)	17.61(0.0001)	8.45(0.004)
	R^2	0.013	0.010	0.008	0.012	0.006
	b_o	0.6548	0.7079	2716.4	4931.4	5745.9
	b_1	-0.08039	-0.08266	-365.1	-720.4	-823.7
BSI Factor 10 - Roadside Distractions	F (Pr > F)	218.88(0.0001)	81.15(0.0001)	28.35(0.0001)	56.19(0.0001)	9.00(0.003)
	R^2	0.134	0.054	0.020	0.038	0.006
	b_o	1.890	1.543	4871.5	9858.3	7785.2
	b_1	-0.4246	-0.3161	-970.9	-2102.6	-1407.6
Total BSI	F (Pr > F)	0.00(0.980)	1.16(0.281)	2.37(0.124)	0.07(0.795)	0.04(0.841)
	R^2	0.0000	0.0008	0.002	0.00005	0.00003
	b_o	0.3630	0.6299	-281.2	1840.9	2156.6
	b_1	-0.00006645	-0.003256	23.69	6.230	7.924

TABLE 57

SUMMARY OF REGRESSION AND ANOVA RESULTS FOR DIVIDED BRIDGES

Variable	Item	Accident/ Year/Bridge	Accident 10^6 Vehicles	Accident Cost/ Accident	Accident Cost/ Year/Bridge	Accident Cost/ 10^6 Vehicles
		BRIDGE CHARACTERISTICS				
Bridge Length	F (Pr > F)	8.08(0.005)*	1.88(0.171)	3.58(0.059)	15.19(0.0001)	7.32(0.007)
	R^2	0.014	0.003	0.006	0.026	0.013
	b_o	1.402	0.4418	3499.5	6516.2	2000.7
	b_1	0.01396	0.0001592	3.499	15.77	3.856
Bridge Roadway Width	F (Pr > F)	26.4(0.0001)	2.53(0.112)	3.73(0.054)	16.79(0.0001)	1.50(0.222)
	R^2	0.044	0.004	0.007	0.029	0.003
	b_o	5.036	0.7355	9297.4	32869.8	5369.6
	b_1	-0.09011	-0.006932	-134.3	-614.5	-65.90
Bridge Lane Width	F (Pr > F)	4.04(0.045)	3.90(0.049)	0.10(0.747)	0.32(0.574)	0.00(0.954)
	R^2	0.007	0.007	0.000	0.001	0.000
	b_o	-2.243	-0.4678	6837.8	824.2	2639.8
	b_1	0.3307	0.07911	-207.0	787.8	25.53
Curb Presence	F (Pr > F)	13.01(0.0001)	12.27(0.0005)	2.49(0.116)	5.55(0.019)	0.83(0.364)
	R^2	0.049	0.024	0.005	0.011	0.002
	b_o	--	--	--	--	--
	b_1	--	--	--	--	--
Degree of Curvature - Bridge	F (Pr > F)	3.26(0.071)	3.20(0.074)	0.23(0.63)	1.43(0.232)	0.26(0.608)
	R^2	0.006	0.006	0.000	0.003	0.000
	b_o	1.670	0.4636	4283.3	9977.2	2885.3
	b_1	0.2534	0.05895	254.6	1394.5	209.5
Maximum Vertical Grade - Bridge	F (Pr > F)	2.72(0.10)	2.80(0.095)	4.66(0.031)	1.30(0.254)	1.86(0.174)
	R^2	0.005	0.005	0.008	0.002	0.003
	b_o	1.568	0.4387	5224.7	11401.3	3370.5
	b_1	0.1755	0.04188	-861.6	-1010.0	-421.4
		APPROACH CHARACTERISTICS				
Degree of Curvature - Approach	F (Pr > F)	13.89(0.0002)	4.26(0.04)	1.18(0.277)	3.19(0.074)	2.10(0.148)
	R^2	0.024	0.007	0.002	0.006	0.004
	b_o	1.489	0.4473	4074.3	9358.3	2654.8
	b_1	0.3243	0.04255	359.3	1301.8	369.9
Tangent Distance	F (Pr > F)	0.00(0.96)	0.04(0.849)	1.11(0.294)	0.68(0.410)	0.94(0.334)
	R^2	0.000	0.000	0.004	0.003	0.004
	b_o	2.069	0.5403	3877.5	10367.4	2909.0
	b_1	5.539×10^{-5}	-4.677×10^{-5}	4.157	6.950	3.339
Sight Distance	F (Pr > F)	3.88(0.049)	1.85(0.174)	2.20(0.139)	1.22(0.271)	1.55(0.214)
	R^2	0.007	0.003	0.004	0.002	0.003
	b_o	3.717	0.7993	-1215.5	1234.2	-672.6
	b_1	-0.002072	-0.000336	5.864	9.638	3.807

* Note. ANOVA significance level (Pr > F) of ≤ 0.01 and the regression coefficient of determination (R^2) values of ≥ 0.02 are underlined for emphasis.

TABLE 57 (Cont'd)

Variable	Item	Accident/ Year/Bridge	Accident 10^6 Vehicles	Accident Cost/ Accident	Accident Cost/ Year Bridge	Accident Cost/ 10^6 Vehicles
Maximum Vertical Grade - Approach	F (Pr > F)	1.33(0.249)	1.11(0.293)	2.11(0.147)	0.29(0.591)	1.54(0.215)
	R^2	0.002	0.002	0.004	0.001	0.003
	b_o	1.595	0.4488	5063.3	10962.2	3412.2
	b_1	0.1014	0.02175	-479.2	-392.1	-316.3
Percent Shoulder Reduction	F (Pr > F)	33.67(0.0001)	11.52(0.0007)	12.0(0.0006)	32.05(0.0001)	7.56(0.006)
	R^2	0.056	0.020	0.021	0.053	0.013
	b_o	1.301	0.4187	3345.9	6791.2	2323.5
	b_1	0.02038	0.002854	46.48	165.1	28.62
Percent Lane Width Reduction	F (Pr > F)	0.04(0.845)	0.93(0.334)	0.49(0.485)	0.11(0.742)	0.13(0.715)
	R^2	0.000	0.002	0.001	0.000	0.000
	b_o	1.725	0.4851	4409.4	10321.7	2967.2
	b_1	-0.006385	-0.007697	-88.85	-91.31	-36.0
Percent Roadway Width Reduction	F (Pr > F)	37.37(0.0001)	10.39(0.0013)	12.01(0.0006)	31.64(0.0001)	7.67(0.006)
	R^2	0.062	0.018	0.021	0.053	0.013
	b_o	1.286	0.4234	3376.2	6853.1	2337.9
	b_1	0.05205	0.006837	117.2	408.2	72.69
Speed Limit Reduction	F (Pr > F)	0.02(0.883)	0.04(0.836)	0.11(0.743)	0.18(0.672)	0.18(0.673)
	R^2	0.000	0.000	0.000	0.000	0.000
	b_o	1.743	0.4812	4367.0	10411.4	2955.8
	b_1	0.02609	-0.008636	-218.4	-622.3	-217.0
OPERATIONAL CHARACTERISTICS						
Speed Limit	F (Pr > F)	7.98(0.005)	5.17(0.023)	0.78(0.377)	0.32(0.574)	0.13(0.720)
	R^2	0.014	0.009	0.001	0.001	0.000
	b_o	8.258	1.7161	-3338.7	21200.5	528.6
	b_1	-0.1194	-0.02265	141.1	-198.3	44.34
Average Daily Traffic	F (Pr > F)	257.5(0.0001)	1.98(0.16)	4.31(0.038)	83.97(0.0001)	0.81(0.368)
	R^2	0.311	0.003	0.008	0.128	0.001
	b_o	0.108	0.5214	3404.5	1668.8	3267.3
	b_1	0.0001462	-3.628×10^{-6}	0.8519	0.7789	-0.02866
Percent Truck	F (Pr > F)	24.22(0.0001)	44.5(0.0001)	1.55(0.214)	3.23(0.073)	2.74(0.098)
	R^2	0.041	0.073	0.003	0.006	0.005
	b_o	2.439	0.6977	5045.1	12555.4	3644.7
	b_1	-0.053	-0.01659	-51.27	-163.4	-52.75
Roadside Distraction	F (Pr > F)	73.95(0.001)	27.41(0.001)	1.34(0.248)	16.39(0.001)	0.72(0.396)
	R^2	0.115	0.046	0.002	0.028	0.001
	b_o	0.024	0.2251	3436.0	3346.0	2423.4
	b_1	0.8616	0.1280	461.6	3525.3	262.0

TABLE 57 (Cont'd)

Variable	Item	Accident/ Year/Bridge	Accident 10^6 Vehicles	Accident Cost/ Accident	Accident Cost/ Year/Bridge	Accident Cost/ 10^6 Vehicles
		BRIDGE SAFETY INDEX FACTOR				
BSI Factor 1 - Clear Bridge Width	F (Pr > F)	0.94(0.333)	1.04(0.308)	0.55(0.458)	1.12(0.291)	1.65(0.200)
	R^2	0.002	0.002	0.001	0.002	0.003
	b_o	7.866	1.997	21998.0	65772.7	26470.8
	b_1	-0.3070	-0.07603	-884.5	-277.1	-1179.5
BSI Factor 2 - Lane Width	F (Pr > F)	2.76(0.097)	3.40(0.066)	0.89(0.346)	1.83(0.176)	0.56(0.455)
	R^2	0.005	0.006	0.002	0.003	0.001
	b_o	0.7146	0.2090	2133.9	3307.6	1582.0
	b_1	0.1023	0.02761	226.0	707.5	138.6
BSI Factor 3 - Barrier Rating	F (Pr > F)	0.08(0.775)	0.64(0.424)	1.30(0.225)	1.20(0.275)	0.16(0.686)
	R^2	0.000	0.001	0.002	0.002	0.000
	b_o	1.950	0.6218	1176.0	3640.3	2076.2
	b_1	-0.01307	-0.008625	196.4	410.2	53.91
BSI Factor 3 - Barrier Rating (Revised)	F (Pr > F)	24.62(0.0001)	21.52(0.0001)	6.02(0.014)	8.58(0.004)	4.23(0.040)
	R^2	0.046	0.040	0.012	0.016	0.008
	b_o	2.767	0.6599	6209.5	15570.0	4130.0
	b_1	-0.07926	-0.01611	-146.5	-392.3	-96.10
BSI Factor 4 - Sight Distance	F (Pr > F)	0.19(0.660)	1.71(0.192)	3.09(0.079)	3.49(0.062)	2.93(0.088)
	R^2	0.000	0.003	0.005	0.006	0.005
	b_o	0.9491	-0.07221	-7531.1	-17516.7	-5996.0
	b_1	0.1618	0.1122	2417.1	5673.4	1817.8
BSI Factor 5 - Tangent Distance	F (Pr > F)	7.37(0.007)	2.46(0.117)	0.05(0.816)	0.95(0.331)	0.48(0.487)
	R^2	0.013	0.004	0.000	0.002	0.001
	b_o	2.754	0.6185	4684.7	13403.6	3700.5
	b_1	-0.2395	-0.03266	-77.56	-716.0	-178.8
BSI Factor 6 - Grade Continuity	F (Pr > F)	0.02(0.897)	0.44(0.507)	0.17(0.680)	0.47(0.492)	0.44(0.508)
	R^2	0.000	0.001	0.000	0.001	0.001
	b_o	1.899	0.2835	6315.0	17552.3	5367.9
	b_1	-0.3353	0.04039	-402.2	-1478.3	-498.2
BSI Factor 7 - Shoulder Reduction	F (Pr > F)	32.6(0.0001)	10.7(0.001)	13.33(0.0003)	33.48(0.0001)	8.12(0.005)
	R^2	0.054	0.018	0.023	0.055	0.014
	b_o	3.805	0.7634	9381.1	27687.4	5990.9
	b_1	-0.4968	-0.06814	-1211.4	-4172.5	-734.1
BSI Factor 10 - Roadside Distraction	F (Pr > F)	73.95 (0.001)	27.41(0.001)	1.34(0.248)	16.39(0.001)	0.72(0.396)
	R^2	0.115	0.046	0.002	0.028	0.001
	b_o	43.332	0.8651	5744.0	20972.5	3733.4
	b_1	-0.8616	-0.1280	-461.6	-3525.3	-262.0
Total BSI	F (Pr > F)	16.93(0.001)	6.52(0.011)	0.07(0.786)	2.75(0.098)	0.51(0.476)
	R^2	0.029	0.011	0.000	0.005	0.001
	b_o	9.808	1.667	6383.9	37665.2	7057.4
	b_1	-0.1026	-0.0151	-25.79	-347.2	-52.32

For instance, a positive correlation between ADT and accident frequency would mean that, as the traffic volume increases, so does the accident frequency.

6.2.1 Bridge Characteristics

For undivided bridges, there is an obvious lack of relationships between bridge characteristics and accident severity expressed in terms of accident cost per accident. The only bridge characteristics with a significant trend is bridge length for which accident severity increases with longer bridges. On the other hand, accident frequency and rate are affected by several bridge characteristics. Higher accident frequency and rate are associated with greater bridge length, presence of curb on the bridge and larger horizontal curvature on the bridge. Greater bridge roadway width is also associated with higher accident frequency. Similar but somewhat weaker relationships exist for accident cost per year per bridge. However, for accident cost per million vehicles, only bridge length shows any significant effect with higher accident cost per million vehicles associated with longer bridge length. This deterioration of relationships for acccident cost measures is likely a reflection on the lack of relationships for accident severity.

For divided bridges, there is a complete lack of relationships between bridge characteristics and accident severity. As for accident frequency, bridge roadway width and curb presence exhibit fairly strong relationships with higher accident frequency associated with narrow bridge width and presence of curbs as well as greater bridge length. Once traffic volume is taken into account with accident per million vehicles, curb presence is the only significant factor. Longer bridge length and narrow bridge width are associated with higher accident cost per year per bridge while only bridge length is positively related to accident cost per million vehicles.

6.2.2 Approach Characteristics

For undivided bridges, there is again a general lack of relationships between accident severity and characteristics at bridge sites except for percent shoulder reduction and percent roadway width reduction which indicates an increase in accident cost per accident with narrower bridges. Greater approach degree of curvature, shorter sight distance, and larger percent shoulder reduction and percent roadway width reduction are related to higher number of accidents per year per bridge and per million vehicles. Larger speed limit reduction is also associated with higher number of accidents per year per bridge, but it is believed that speed limit reduction is actually the result of high accident frequency experienced and not vice versa. Again, similar but weaker relationships are observed for the accident cost measures as compared to accident frequency and rate measures.

For divided bridges, the results are very similar to those of undivided bridges but with stronger influence from narrowness of bridges, both in terms of percent shoulder reduction and percent roadway width reduction. Horizontal alignment, expressed in degree of curvature and sight distance, has much less effect on divided bridges than undivided bridges as expected since divided roadways are designed to higher standards than undivided roadways.

6.2.3 Operational Characteristics

It is well known that average daily traffic (ADT) is the single most predominant factor affecting accident frequency and the results from this study again confirm that relationship. For undivided bridges, ADT also has positive relationships with accident rate, accident severity, and the accident cost measures, but not so for divided bridges except for accident cost per year per bridge.

Roadside distraction has relatively strong positive association with all five accident frequency, rate, severity, and accident cost measures for undivided bridges. This is somewhat surprising since roadside distraction is rated on a subjective basis within a narrow range of ratings (1 to 5). However, roadside distraction does correlate weakly to ADT ($r = 0.45$) which may contribute to part of its strength. Also, roadside distraction may be a proxy measure for other factors that are associated with accidents at bridge sites, but are not included in the evaluation, such as number of access points, land use patterns, etc. The effects of roadside distraction on accident frequency and rate and accident costs per year per bridge are also present, though somewhat weaker, for divided bridges, but are insignificant for accident severity and accident costs per million vehicles.

Both speed limit and percent trucks have negative relationships with accident frequency and rate, but not with accident severity or accident cost measures. Speed limit has more influence on undivided bridges while percent truck has greater effect on divided bridges.

6.2.4 Bridge Safety Index (BSI) Factors

The BSI factors are mostly derived from bridge, approach, and operational characteristics. Thus, it is not surprising to see that most of the relationships for BSI factors are similar to those of bridge, approach, and operational characteristics discussed above. The only truly new factor is BSI Factor 3 - Barrier Rating. Two different barrier rating systems were tried in the study. One deals strictly with presence/absence of bridge rail, guardrail, transition and end treatment while the other (revised Factor 3) evaluates the same features but from the standpoint of conformity with current standards. For undivided bridges, the presence/absence of such barriers and features is more important to the accident measures while the conformity to current standards criterion is more significant for divided bridges. Regression results for both definitions are shown in Tables 56 and 57. However, the conformity to current standards criterion is used for all further analysis.

BSI Factors 8 (Volume/Capacity Ratio) and 9 (Traffic Mix) were not included in the total BSI because of difficulties in establishing their values from available data. The total BSI, as used in the evaluation, thus includes only 8 of the 10 factors though it accounts for 89.5% (85/95) of the total possible score. To aid in the evaluation of the two missing factors, ADT and percent truck are used as surrogate measures. As it turns out, both ADT and percent truck turn out to be key factors affecting accidents at bridge sites. It appears that the weight given to each of these two factors (5/95) is too low to accurately reflect their importance.

The combined or total BSI is significant only for accidents per year per bridge for divided bridges while many of the individual factors are significant in their relationships. One may argue that the exclusion of Factors 9 and 10 may be the cause for such lack of significance for the total BSI. However, with nearly 90 percent of the total possible score accounted for, it is felt that the results from this evaluation will be close enough to reflect on the complete BSI. The real reason appears to be that of "wash-out" among the individual factors.

Take accidents/year/bridge for undivided bridges as an example. Three of the eight factors (1, 3 and 6) show positive associations while the other five factors (2, 4, 5, 7 and 10) are negative. The total BSI also shows a negative correlation, but the "wash-out" effect is apparent.

TABLE 58

RESULTS OF DISCRIMINANT ANALYSIS ON ACCIDENT FREQUENCY FOR BRIDGE, APPROACH, OPERATIONAL AND COUNTERMEASURE CHARACTERISTICS

	ACCIDENT FREQUENCY					
	Undivided Bridges			Divided Bridges		
Variable	Step	Standardized	Unstandardized	Step	Standardized	Unstandardized
Bridge Length	6	0.1509	0.7996×10^{-3}	8	0.1443	0.6319×10^{-3}
Bridge Width						
Curb Presence	5	0.1334	0.2751			
° Curvature - Bridge	4	0.1746	0.1629			
% Grade - Bridge				6	-0.1601	-0.1539
° Curvature - Approach	7	0.1401	0.03278			
Sight Distance						
% Grade - Approach						
Speed Limit				7	0.1487	0.05819
Roadside Distraction	2	0.3357	0.4016	2	0.5761	0.5926
Signing						
Marking	8	0.1239	0.2261			
Delineator						
BSI				5	0.2094	0.04796
% Shoulder Reduction	3	0.2180	0.5661×10^{-2}	3	0.4206	0.01418
Urban/Rural						
ADT	1	0.7013	0.3817×10^{-3}	1	0.4461	0.4849×10^{-4}
% Truck						
Barrier Rating				4	-0.4022	-0.05629
Constant			-2.0100			-8.2683

Undivided Bridges			Divided Bridges		
Group	Description	Centroid	Group	Description	Centroid
0	No Accident	-0.4158	0	No Accident	-0.9182
1	Accident	1.6610	1	Accident	0.4804

Undivided Bridges

Actual Group	Weighted N	Predicted Group 0	Predicted Group 1
0	5259 80.0%	5086 96.7%	173 3.3%
1	1316 20.0%	605 46.0%	710 54.0%

Total Correct Classification = 88.2%

Divided Bridges

Actual Group	Weighted N	Predicted Group 0	Predicted Group 1
0	361 33.2%	218 60.5%	142 39.5%
1	727 66.8%	104 14.4%	623 85.6%

Total Correct Classification = 77.3%

TABLE 59

RESULTS OF DISCRIMINANT ANALYSIS ON ACCIDENT SEVERITY

	ACCIDENT SEVERITY					
	Undivided Bridges			Divided Bridges		
Variable	Step	Standardized	Unstandardized	Step	Standardized	Unstandardized
Bridge Length						
Bridge Width	2	-0.6175	-0.08803	4	0.9455	0.1491
Curb Presence	5	-0.3766	-0.8767			
° Curvature - Bridge	7	0.2143	0.1021			
% Grade - Bridge						
° Curvature - Approach	4	0.3230	0.04524			
Sight Distance				5	0.3313	0.3298×10^{-2}
% Grade - Approach						
Speed Limit	3	0.5321	0.06491	7	-0.1625	-0.05784
Roadside Distraction				8	-0.1393	-0.1381
Signing				6	0.2312	0.8999
Marking	6	0.3077	0.5967			
Delineator						
BSI						
% Shoulder Reduction				1	1.2402	0.03816
Urban/Rural						
ADT	1	0.7266	0.2210×10^{-3}	3	0.5549	0.5178×10^{-4}
% Truck				2	0.3994	0.04323
Barrier Rating						
Constant			-2.0838			-7.4370

Undivided Bridges			Divided Bridges		
Group	Description	Centroid	Group	Description	Centroid
0	No (K + A) Injuries	-0.1789	0	No (K + A) Injuries	-0.3856
1	(K + A) Injuries	0.2372	1	(K + A) Injuries	0.4566

Actual Group	Weighted N	Predicted Group 0	Predicted Group 1	Actual Group	Weighted N	Predicted Group 0	Predicted Group 1
0	761 57.9%	658 86.4%	104 13.6%	0	395 54.3%	293 74.3%	102 25.7%
1	553 42.1%	398 72.0%	155 28.0%	1	332 45.7%	149 44.9%	183 55.1%

Total Correct Classification = 61.8%   Total Correct Classification = 65.5%

Despite six of the eight factors being related to the accident frequency, the total BSI is not. It seems appropriate to have the effects of all the individual factors moving in the same direction instead of canceling each other out. Also, some revision in the relative weights of the factors may be appropriate after their relative importance to accidents are established from this study.

6.3 Hazardous vs. Non-Hazardous Bridges

One key question to be addressed by this study is whether one can distinguish hazardous from non-hazardous bridges and if so, what are the major differences between them. Discriminant analysis was used to address this question in two steps. The first step is to discriminate between bridges without accidents to those with accidents. Then, for those bridges with accidents, the second step is to distinguish between bridges with no K (fatal) and A (incapacitating) injury accidents to those with (K + A) injury accidents. Tables 58 and 59 summarize the results of the discriminant analysis for accident frequency and severity, respectively. Additional breakdowns by urban versus rural and narrow versus non-narrow categorizations for undivided and divided bridges are presented in Tables A.151 through A.162.

A maximum of eight steps is allowed for variables to enter into or be removed from the discriminant function in a stepwise manner with a partial F ratio of 1.0 as the criterion. As it turned out, the maximum of eight variables is entered into all of the discriminant functions. The choice of eight steps as the maximum with a partial F ratio of 1.0 is admittedly arbitrary in nature. However, it should be pointed out that the main aim of the discriminant analysis is to identify those variables that help to distinguish hazardous from non-hazardous bridges and not necessarily statistical significance, which would have to be based on the assumption of a multivariate normal distribution. Therefore, the results of the discriminant analysis should be viewed as an indication of the effects of independent variables on the probability of accident frequency and accident severity and not strictly as predictive equations.

As explained in Appendix E, the mathematical objective of discriminant analysis is to select, weight, and linearly combine a set of so-called discriminating variables that can best statistically distinguish between the two groups under consideration, e.g., bridges with and without accidents. The variables are selected in a stepwise manner so that the most discriminating variable is selected at each step. The relative weights or importance of the discriminating variables are expressed in the form of standardized coefficients, in which each variable is standardized or normalized to a mean of 0 and a standard deviation of 1. A classification score can then be calculated by linearly combining the products of the standardized coefficients and the standardized values of the discriminating variables.

However, since the field data of the discriminating variables rarely has a standardized (0.1) normal distribution, a set of unstandardized coefficients are provided to allow for calculation of the classification score from field data. In simple terms, the standardized coefficients reflect the relative importance of the variables while the unstandardized coefficients are used to calculate the classification score using field data.

For the two groups under consideration, each has a centroid under the assumption of a multivariate normal distribution (similar to the mean for a univariate normal distribution). By comparing the calculated classification score to the group centroids, one may determine the probabilities of a bridge belonging to either of the two groups. The measure of success is how well the predicted group memberships compare to the actual group memberships. More discussions on this will be presented later in this section.

6.3.1 Accident Frequency

The sampling plan used in selecting sample bridges from the bridge population as defined in the study was specifically designed for such comparison between bridges with no accidents (group 0) and those with accidents (group 1). The results of the discriminant analysis on accident frequency are very good considering the large variability in the data.

For undivided bridges as shown in Tables 58 and 59, the discriminant variables are, in order of descending importance: ADT, roadside distraction, percent shoulder reduction, degree of curvature on the bridge, curb presence, bridge length, degree of curvature on the approach and longitudinal marking. The predominance of ADT on accident frequency is evident with the relative weight (standardized coefficient) of 0.7013 comparing to those of other variables ranging from 0.1239 to 0.3357. With the centroid for bridges with no accidents being negative (-0.4158) while the coefficients for all eight discriminant variables are positive, it indicates that increases in values for the discriminant variables will increase the probability of accidents on the bridge.

The actual distribution for accident frequency on undivided bridges is 80 percent with no accidents and 20 percent with accidents. Theoretically speaking, if one randomly assigns bridges to the two groups 0 and 1, 80 percent should fall into group 0 and 20 percent into group 1. The discriminant function has greatly improved the odds, especially in identifying bridges with no accidents. For bridges actually with no accidents, 96.7 percent are classified correctly as compared to 80 percent if assigned randomly. For bridges actually with accidents, 54 percent are correctly predicted which is not too bad considering that only 20 percent of the bridges actually have accidents. Overall, 88.2 percent of the bridges are correctly classified.

To illustrate how the discriminant function may be applied, consider the hypothetical example shown in Table 60. The hypothetical bridge has a classification score of -0.63754, which is more negative than the centroid for bridges with no accidents (group 0) of -0.4158. The hypothetical bridge is therefore classified in group 0, i.e., predicted to have no accidents.

For divided bridges, the first three discriminant variables remain the same as for undivided bridges, i.e., ADT, roadside distraction and percent shoulder reduction. The remaining five variables are different, including barrier rating, BSI, percent grade on bridge, speed limit, and bridge length. The coefficients for barrier rating and percent grade on bridge are negative while those for the remaining six variables are positive. Since the centroid for group 0 is negative, this suggests that higher barrier rating and steeper grade on the bridge will decrease the probability of accidents on the bridges while increases in the values of the other six variables will increase the probability of accidents.

The discriminant function for divided bridges is not as strong as that for undivided bridges with correct classification on 77.3 percent of the bridges. For bridges actually with no accidents, only 60.5 percent are predicted correctly while that for bridges actually with accidents is 85.6 percent. The actual distribution is 33.2 percent of the bridges with no accidents.

TABLE 60

HYPOTHETICAL EXAMPLE TO ILLUSTRATE THE APPLICATION OF THE DISCRIMINANT FUNCTION

Consider an undivided bridge with the following actual values on the discriminant variables.

Variable	Actual Value	Unstandardized Coefficient	Product
Bridge Length	100 feet	0.7996×10^{-3}	0.07996
Curb Presence	Level (0)	0.2751	0
° Curvature - Bridge	Straight (0)	0.1629	0
° Curvature - Approach	Straight (0)	0.03278	0
Roadside Distraction	Few (1)	0.4016	0.4016
Longitudinal Marking	Centerline Only (1)	0.2261	0.2261
% Shoulder Reduction	50%	0.5661×10^{-2}	0.2831
ADT	1,000	0.3817×10^{-3}	0.3817
Constant		-2.0100	-2.0100
		Classification Score =	-0.63754

Since the centroid of bridges with no accidents (group 0) is -0.4158 while the classification score for this bridge is even more negative, this bridge is classified in group 0, i.e., predicted to have no accidents.

6.3.2 Accident Severity

Bridges with accidents were divided into two groups for assessment of accident severity: those with no (K + A) injury accidents versus those with (K + A) injury accidents. The results of the discriminant analysis are very poor, especially for undivided bridges. The total correct classification for both undivided and divided bridges is only in the 60 percent range. This supports the earlier finding that the severity of accidents on bridges is little affected by the physical and operational characteristics at the bridge sites.

6.3.3 Urban vs. Rural Bridges

Tables A.151 and A.152 in Appendix M illustrate the results of discriminant analysis on urban versus rural undivided bridges. With the predominance of undivided bridges in rural areas, the results for rural undivided bridges are very similar to those for all undivided bridges. However, for urban undivided bridges, the results are somewhat different. The actual bridge width replaces percent shoulder reduction as one of the key factors. Also, percent truck and barrier rating are entered into the function, reflecting the increase of trucks in the traffic mix and greater use of barriers in urban areas. Roadside distraction in urban areas has less influence on accident frequency than in rural areas.

For divided bridges, as shown in Tables A.153 and A.154, the split between urban and rural areas is more even though still favoring the rural area. Again, the increase in truck traffic for urban areas is reflected in the discriminant function. Roadside distraction is not even entered into the function for urban divided bridges.

Results of discriminant analysis on accident severity are somewhat better when urban and rural bridges are analyzed separately, but are still too weak for much practical use.

6.3.4 Narrow vs. Non-Narrow Bridges

Tables A.155 through A.162 summarize the results of discriminant analysis on narrow versus non-narrow bridges for undivided and divided bridges. For undivided bridges, a further breakdown into bridges with widths of 24 feet or less and bridges wider than 24 feet is also included. The purpose is to evaluate if accident occurrence on narrow bridges is affected by different bridge, approach, and operational characteristics from those for non-narrow bridges.

In general, the results of the discriminant analysis are better after the breakdown into narrow and non-narrow bridges with wider separation of the group centroids (i.e., clearer distinction between the groups) and higher percentage of correct classification. However, even with the improvement, the results on accident severity are still too weak for any meaningful application, indicating the general lack of relationships between accident severity and characteristics of bridge sites.

As discussed previously under Table 55, there are some major differences on bridge, approach and operational characteristics between narrow and non-narrow bridges and between undivided bridges with widths 24 feet or less and bridges wider than 24 feet. These differences are clearly manifested in the results of the discriminant analysis.

For narrow undivided bridges, the probability of accident occurrence increases with greater values of ADT, roadside distraction, presence of curb, bridge length, bridge and approach degree of curvature, and presence of longitudinal marking, but decreases with wider bridge width. For non-narrow undivided bridges, ADT, roadside distraction, bridge degree of curvature and bridge length remain in the discriminant function. Approach horizontal alignment is still represented by sight distance, replacing approach degree of curvature. The same is true for traffic control devices with delineator/object marker in place of longitudinal marking. The key differences are bridge width and curb presence which apply only to narrow bridges while urban/rural and speed limit are more important to the probability of accident occurrence on non-narrow bridges.

Bridge width is dropped from the accident frequency discriminant function for undivided bridges 24 feet or less in width while the same applies to curb presence and bridge degree of curvature for bridges wider than 24 feet. The only new entry is the percentage of trucks in the traffic mix for non-narrow bridges 24 feet or less in width.

As for divided bridges, there are more widespread differences between the characteristics of narrow and non-narrow bridges which are also reflected in the discriminant functions. For narrow divided bridges, the probability of accident occurrence increases with higher degree of roadside distraction, presence of curb, smaller approach degree of curvature, higher ADT, lower barrier rating, longer bridge length, higher speed limit, and presence of longitudinal marking. For non-narrow divided bridges, only ADT, roadside distraction, and barrier rating remain in the function. Approach horizontal alignment with sight distance replacing approach degree of curvature and traffic control devices with signing and delineator/object marker presence in place of longitudinal marking are also present in the function. The key changes are percent truck in the traffic stream and bridge degree of curvature for non-narrow divided bridges, displacing bridge length and curb presence for narrow divided bridges.

The general lack of relationships between accident severity and characteristics of bridge sites are again evident with substantial changes in the variables entered into the discriminant functions for various stratification of undivided/divided and narrow/non-narrow bridges. The changes are erratic with no apparent trends and little practical application of the discriminant function is anticipated.

6.4 Accident Bridges

While bridges with accidents can be distinguished reasonably well from those without accidents as discussed in the previous section, attempts to relate the accident frequency, rate, and severity measures to characteristics at bridge sites with accidents are met with much less success. Stepwise multiple linear regression analysis was conducted to relate bridge, approach, operational, and countermeasure characteristics to the five accident frequency, rate, and severity measures, the results of which are shown in Tables 61 and 62 for undivided and divided bridges, respectively. Results of regression analysis on urban/rural and narrow/non-narrow categorizations of undivided and divided bridges are shown in Tables A.163 through A.174.

For each regression equation, the steps at which the variables entered into the equation are shown together with the associated change in the coefficient of determination, R^2, and the regression coefficients for each of the variables. The total R^2 for the equation and the F ratio are also given. The criterion for including a variable into the equation is a R^2 change of 0.005 or greater. However, a minimum of 5 and a maximum of 10 variables are allowed for each regression equation regardless of the R^2 change.

The inclusion of at least five variables into the regression equations may render some of the variables entered into the equations being insignificant (i.e., their regression coefficients are not significantly

TABLE 61

SUMMARY OF REGRESSION RESULTS FOR BRIDGE, APPROACH, OPERATIONAL, AND COUNTERMEASURE CHARACTERISTICS ON UNDIVIDED BRIDGES WITH ACCIDENTS

	Accident/Year/Bridge			Accident/10^6 Vehicles			Accident Cost/Accident			Accident Cost/Year/Bridge			Accident Cost/10^6 Veh		
Variable	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient
Bridge Length															
Bridge Width				7	0.0081	-0.03401							5	0.0160	-192.66
Curb Presence				6	0.0081	-0.5597	4	0.0053	-23.077				4	0.0126	-3073.8
° Curvature - Bridge				3	0.0288	0.1607	3	0.0029	-322.80				3	0.0136	512.70
% Grade - Bridge	4	0.0084	0.1186							3	0.0197	480.18			
° Curvature - Approach				9	0.0063	0.02585									
Sight Distance	3	0.0127	-0.7792×10^{-3}										6	0.0053	-3.4479
% Grade - Approach															
Speed Limit				4	0.0104	-0.02494	5	0.0030	12.185						
Roadside Distraction	5	0.0043	0.1265	5	0.0112	-0.1835							7	0.0068	-723.53
Signing															
Marking				10	0.0051	-0.2803	2	0.0024	231.43	4	0.0120	1176.2			
Delineator															
BSI	2	0.0392	-0.02801	2	0.0564	-0.01509				2	0.0430	-123.33	2	0.0335	-67.692
% Shoulder Reduction										5	0.0044	9.9435			
Urban/Rural															
ADT	1	0.1708	0.2357×10^{-3}	1	0.1903	-0.1946×10^{-3}				1	0.1439	0.6469	1	0.1279	-0.7022
% Truck							1	0.0209	28.556						
Barrier Rating				8	0.0068	-0.02534									
Constant			3.0903			7.3448			3054.08			9176.5			26517.8
R^2		0.2355			0.3314			0.0344			0.2231			0.2158	
F Ratio		75.90			60.83			8.78			70.77			48.34	

TABLE 62

SUMMARY OF REGRESSION RESULTS FOR BRIDGE, APPROACH, OPERATIONAL, AND COUNTERMEASURE CHARACTERISTICS ON DIVIDED BRIDGES WITH ACCIDENTS

	Accident/Year/Bridge			Accident/10^6 Vehicles			Accident Cost/Accident			Accident Cost/Year/Bridge			Accident Cost/10^6 Veh		
Variable	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient	Step	R^2 Change	Coefficient
Bridge Length													5	0.0043	0.5856
Bridge Width				8	0.0070	0.01811	3	0.0139	67.157	5	0.0044	213.85	4	0.0262	126.25
Curb Presence							5	0.0046	-356.30						
° Curvature - Bridge															
% Grade - Bridge	5	0.0046	0.1825	6	0.0068	0.03939									
° Curvature - Approach	2	0.0306	0.3197	4	0.0136	0.04989				2	0.0215	852.44	2	0.0187	207.33
Sight Distance							4	0.0089	1.8896						
% Grade - Approach															
Speed Limit	4	0.0087	-0.1036	3	0.0191	-0.03536									
Roadside Distraction										4	0.0060	705.16			
Signing															
Marking				5	0.0070	0.2211									
Delineator							6	0.0055	-292.60						
BSI															
% Shoulder Reduction				7	0.0040	0.4240×10^{-2}	2	0.0111	18.380	3	0.0064	60.612	3	0.0072	25.148
Urban/Rural															
ADT	1	0.2028	0.1112×10^{-3}	1	0.1227	-0.2122×10^{-4}				1	0.2204	0.3655	1	0.0846	-0.05548
% Truck	3	0.0139	-0.03077	2	0.0354	-0.9175×10^{-2}	1	0.0231	19.823						
Barrier Rating															
Constant			6.5948			1.7534			-1302.8			-8766.2			-2668.5
R^2		0.2605			0.2156			0.0670			0.2587			0.1410	
F Ratio		45.73			22.19			7.76			45.30			21.30	

different from zero statistically), particularly for those concerning accident severity. However, the variables are still included in the equations to provide the reader with some ideas on the relationships even though they may be too weak to be statistically significant. These variables are easily identified with R^2 change of less than 0.005.

It should be emphasized that the regression results are not intended as rigid statistical tests based on normality assumptions or significance levels. The equations merely indicate relationships between the dependent and independent variables and what effects certain changes in the independent variables have on the dependent variables. This may then suggest certain modifications leading to possible reductions in the frequency or severity of bridge accidents.

6.4.1 Undivided Bridges With Accidents

As shown in Table 61, the number of accidents per year per bridge increases with higher ADT, steeper grade, and more roadside distraction, but decreases with greater BSI and longer sight distance. Average daily traffic is the predominant factor, accounting for 17 percent of the 23.55 percent of sample variation explained by the regresssion equation. It should be noted that the variables affecting the accident frequency for bridges with accidents are not necessarily the same as those discriminating between bridges with accidents to those without accidents, as shown in Table 58.

The number of accidents per million vehicles for undivided bridges with accidents decreases with increasing ADT, BSI, speed limit, roadside distraction, curb presence, bridge width, barrier rating, and longitudinal marking, but increases with greater degree of curvature on the bridge and approach. The overall R^2 value for the equation is 33.14 percent of which 19 percent is attributed to ADT value.

The regression result for accident severity on undivided bridges with accidents is very poor with slightly over 3 percent of the sample variation explained by the equation. This is consistent with the analysis results on individual factors and from discriminant analysis, which all indicate that accident severity of bridge accidents is little affected by all the physical or operational characteristics at bridge sites.

Since the accident cost measures are composite measures of accident frequency/rate and severity, the regression results for accident cost measures are, as expected, not as good as those for accident frequency or rate measures. The R^2 values for the equations are lowered to around 22 percent of the sample variations. Average daily traffic remains the predominant factor accounting for the majority of the R^2 values. There are slight changes in the variables entered into the equations, but overall are very similar to those on accident frequency and rate.

6.4.2 Divided Bridges with Accidents

The number of accidents per year per bridge increases with higher ADT, greater approach degree of curvature and steeper grade on the bridge, but decreases with higher percent truck and speed limit, as shown in Table 62. The overall R^2 value of the equation is 26 percent. The same five variables are also entered into the regression equation for number of accidents per million vehicles except that ADT has a negative coefficient. Three more variables are added to the equation indicating increasing accident rate with longitudinal marking presence, greater bridge width and percent shoulder reduction. It should be noted that the variables bridge width and percent shoulder reduction are highly correlated and they partially cancel out each other's effect.

The R^2 value for the regression equation on accident severity imposed slightly to 6.7 percent of the sample variation, but is still too low to attach any significance to it. Higher accident severity is associated with greater percent truck, shoulder reduction, roadway width and sight distance, but decreases with curb and delineator presence.

The combination of accident frequency/rate and severity resulted in some changes to the relationships between independent variables and accident cost measures. ADT and approach degree of curvature remain the two key variables. Percent shoulder reduction and bridge width are added to the equations while percent truck is excluded. The R^2 values drop lower for accident cost measures than their accident frequency/rate counterparts, with only 14.1 percent for accident costs per million vehicles.

6.4.3 Urban Versus Rural Bridges

Tables A.163 through A.166 in Appendix M present the regression analysis results for urban/rural undivided/divided bridges. The results for rural undivided bridges are very similar to those for overall undivided bridges, but those for urban undivided bridges are very different.

The maximum of 10 variables are entered into most regression equations for urban divided bridges with relatively high R^2 values. Average daily traffic continues to be a predominant factor and its contribution to the overall R^2 values remains relatively unchanged in absolute terms. However, with the higher overall R^2 value, variables other than ADT are contributing more to the explanation of the sample variations.

There are some variations in the regression results between urban, rural, and combined divided bridges. However, the patterns are not too clear-cut for any conclusions to be drawn regarding their differences. Overall, the R^2 values are relatively low indicating weak relationships.

6.4.4 Narrow Versus Non-Narrow Bridges

Tables A.167 through A.174 summarize the regression analysis results on narrow and non-narrow bridges for undivided and divided bridges. In general, the results are better with the narrow/non-narrow categorization in terms of the R^2 values. As in the case with discriminant analysis, there are some marked differences in the variables entered into the regresson equations between narrow and non-narrow bridges.

For narrow undivided bridges, the number of accidents per year per bridge increases with higher ADT, reduced sight distance, lower BSI, steeper grade on the bridge, and decrease in the percentage of trucks, with an overall R^2 value of 20.9 percent. Average daily traffic remains on the predominant factor (accounting for 22.6 of the total 35.6 percent R^2 value) for number of accidents per million vehicles which decreases with higher ADT. Approach degree of curvature replaces sight distance while BSI and percent grade on bridge remain in the equation. Percent truck drops out of the equation, but three new variables are entered so that the number of accidents per million vehicles also increases with absence of curb, greater bridge degree of curvature, and absence of longitudinal marking.

Except for ADT and bridge degree of curvature, the regression variables of non-narrow undivided bridges are totally different from those of narrow undivided bridges for both number of accidents per year per bridge and per million vehicles. The major differences for the regression equations of non-narrow undivided bridges are the inclusion of bridge width and roadside distraction and the exclusion of percent grade on bridge and approach horizontal alignment.

When undivided bridges are further divided into 24 feet or less in width and are wider than 24 feet, the results of the regression analysis in terms of R^2 value further improve. However, except for ADT, the regression variables vary substantially between narrow and non-narrow undivided bridges and between those 24 feet or less in width and those wider than 24 feet.

There are also considerable differences between the regression variables of narrow and non-narrow divided bridges. The number of accidents per year per bridge for narrow divided bridges increases with higher values of ADT, approach degree of curvature, and percent grade for approach, but decreases with higher speed limit and percent truck. Two more variables are added to the regression equation for number of accidents per million vehicles, including bridge degree of curvature and longitudinal marking while percent grade on approach drops out. Also, the sign for ADT is reversed so that higher ADT is associated with increasing number of accidents per year per bridge, but with decreasing number of accidents per million vehicles.

For non-narrow divided bridges, the inclusion of bridge length and width and percent grade on the bridge plus the exclusion of percent grade in the approach and percent truck are perhaps the key changes compared to narrow divided bridges. Again, the regression equation for accidents per million vehicles has more variables than accidents per year per bridge, but the major variables remain unchanged except for the sign reversal of ADT.

The regression equations for accident severity still have very low R^2 values with substantial changes in variables between narrow and non-narrow bridges. The patterns are rather erratic with no apparent trends. Regression equations for the accident cost measures generally follow those of accident frequency and rate and have slightly lower R^2 values.

6.5 Summary

This chapter has delineated the statistical techniques used and described the processes followed to select the independent and dependent variables for analysis purposes. Of interest have been the relationships between accident frequency and severity with bridge design and operational characteristics and the geometrics and conditions of their approaches.

6.5.1 Individual Bridge Factors

Individual bridge, approach, operational, and countermeasure characteristics and the bridge safety index factors were investigated to identify relationships and significance, if any, to accident frequency, rate, and severity measures. Result summaries follow:

- For undivided bridges, there is an obvious lack of relationships between bridge characteristics and accident severity except for bridge length, where severity increases with bridge length. For divided bridges, there is a complete lack of relationships.

- Higher accident frequency and rate for undivided bridges are associated with greater bridge length, presence of curb and larger horizontal curvature on the bridge, and greater bridge roadway width. For divided bridges, accident frequency increases with decrease in bridge width, presence of curbs, and greater bridge length. For accident rate, curb presence is the only significant factor.

- For all bridges, a general lack of relationships exists between accident severity and approach characteristics except for percent shoulder reduction and percent roadway width reduction, with a stronger influence for the divided structures.

- Greater approach degree of curvature, shorter sight distance, and larger percentages of shoulder reduction and roadway width reduction are related to higher frequencies and rates. Curvature and sight distance have less effect on divided bridges than on undivided ones.

- As expected, ADT is the most predominant factor affecting accident frequency. For undivided bridges, ADT also has positive relationships with accident rate and severity.

- Roadside distractions have relatively strong positive association with accident frequency, rate, and severity for all bridges, though somewhat weaker for the divided structures.

- Speed limit and percent trucks have negative relationships with accident frequency but positive association with accident severity.

- The total bridge safety index (BSI) is significant only for accident rate on divided bridges. Individual BSI factors are significant in some cases but tend to cancel each other out in the combined total.

6.5.2 Hazardous vs. Non-Hazardous Bridges

Discriminant analysis was used to determine if a distinction could be made between hazardous and non-hazardous bridges. Result summaries follow:

- For undivided bridges, the discriminant variables, in the order of descending importance, are ADT, roadside distraction, percent shoulder reduction, bridge degree of curvature, curb presence, bridge length, approach degree of curvature, and longitudinal marking. Increases in these variables increase the probability of accidents on such bridges.

- For divided bridges, the discriminant variables are ADT, roadside distraction, percent shoulder reduction, barrier rating, BSI, bridge percent grade, speed limit, and bridge length. Higher barrier rating and steeper grades decrease the probability of accidents on such bridges. Increases in the other six variables increase the probability.

- The severity of accidents on bridges is little affected by the physical and operational characteristics at the bridge sites.

- The results of the discriminant analyses are slightly better when bridges in urban and rural areas are considered separately. With the predominance of bridges in rural areas, the results for rural bridges are similar to those for all bridges, but not so for bridges in urban areas. The major differences reflect the increase of trucks in the traffic mix in urban areas while roadside distraction has much less influence on accident occurrence on urban bridges. Also, for undivided bridges, the more frequent use of barriers in urban areas is manifested in the discriminant function. As for accident severity, the results also improve slightly with the urban/rural breakdown, but are still too weak for much practical use.

- When narrow and non-narrow bridges are evaluated separately, the results of the discriminant analyses are better with clearer distinction between bridges with and without accidents or (K + A) injuries and higher percentage of correct classification. However, even with the improvements, the results on accident severity are still too weak for any meaningful application, again reflecting the general lack of relationships. As for accident frequency, the key differences between narrow and non-narrow undivided bridges are bridge width and curb presence which are more important for narrow bridges while urban/rural and speed limit are more important for non-narrow bridges. For divided bridges, the differences between narrow and non-narrow bridges are more widespread with the key changes on percent truck in the traffic stream and bridge horizontal alignment for non-narrow divided bridges, displacing bridge length and curb presence for narrow divided bridges.

6.5.3 Accident Bridges

Stepwise multiple linear regression analysis was conducted to relate bridge, approach, operational, and countermeasure characteristics to accident frequency, rate, and severity measures for bridges with accidents. Result summaries follow:

- For undivided bridges with accidents, accident frequency increases with higher ADT, steeper grade, and more roadside distraction, and decreases with greater BSI and longer sight distance. Accident rates decrease with increasing ADT, BSI, speed limit, roadside distraction, curb presence, bridge width, barrier rating, and longitudinal marking, and increase with greater bridge and approach degrees of curvature. Regression results for accident severity are poor, again indicating that accident severity is little affected by the physical and operational characteristics.

- For divided bridges with accidents, accident frequency increases with higher ADT, greater approach degree of curvature, and steeper bridge grade, and decreases with higher percent truck and speed limit. Accident rates are similar except that ADT has a negative coefficient and longitudinal marking presence, greater bridge width, and percent shoulder reduction increase the rate. Correlation of accident severity is still too low for practical significance.

- Regression equations for the accident cost measures usually follow those of accident frequency and rate, but with slightly lower R^2 values. This reflects the general lack of relationships for accident severity which combines with accident frequency and rate to form the accident cost measures.

- When bridges with accidents in urban and rural areas are considered separately, the regression results for the rural undivided bridges are again very similar to those for all undivided bridges, but those for urban divided bridges are very different. The maximum of 10 variables is entered into most regression equations for urban undivided bridges with relatively high R^2 values, suggesting that accident occurrence in urban areas is affected by more factors in addition to ADT. The regression results for divided bridges are too scattered for any conclusions to be drawn between urban and rural divided bridges.

- Breakdown into narrow and non-narrow categories for bridges with accidents generally produces better regression results. As in the case with discriminant analysis, there are some marked differences in the variables entered in the regression equations between narrow and non-narrow bridges on accident frequency and rate. As for accident severity, the regression equations have very low R^2 values with substantial changes in variables between narrow and non-narrow bridges.

CHAPTER VII. CONCLUSIONS AND RECOMMENDATIONS

7.1 Findings and Conclusions

The results of the study are based on three separate data files developed during the course of the study.

1. POPULATION File - The file contains bridge, roadway, and traffic data on 11,880 bridges from five States (Arizona, Michigan, Montana, Texas, and Washington) with 24,809 associated accidents.

2. SAMPLE File - The file contains a sample of 1,989 bridges, including 1,396 (6,574 weighted) two-lane undivided bridges and 593 (1,088 weighted) two-lane divided twin structures.

3. ACCIDENT File - The file contains data on 124 bridge accidents investigated in-depth.

Brief summaries of significant findings and conclusions from the study are presented in the following subsections.

7.1.1 General

- Wide variations and inconsistencies in data definition, coding, and formatting existed between the study States and sometimes within the States. These discrepancies required major screening and code transformation efforts in merging files from several States into consistent data bases for use in the study.

- Accidents were matched to the bridges using a milepoint matching process. Due to inaccuracies with accident locations, it is not possible to pinpoint the exact location of an accident in relation to the bridge itself. However, it can be identified as occurring within the immediate vicinity of the bridge and its approaches with reasonable confidence.

- Evaluation on the effectiveness of countermeasures for bridge sites is severely hampered by the lack of accurate and readily available information on the countermeasures, such as the nature and date of countermeasure installation. Also, the experimental design used in the study is not sensitive enough to detect the subtle effects of countermeasures. A before-and-after with control experimental design would be more appropriate.

- There are some definitional problems associated with the use of shoulder reduction as the sole indicator of bridge narrowness. Since shoulder reduction is primarily a function of approach shoulder width, a bridge with no approach shoulder would automatically be classified as non-narrow provided that the width criterion is met. Also, there are likely some marked differences between bridges with wide and narrow approach shoulders even though they may have the same percentage of shoulder reduction.

7.1.2 General Bridge Characteristics

POPULATION File

- Since only bridges on State highway systems are included in the study, over 90 percent of the bridges are in rural areas and 81.7 percent of the bridges are two-lane undivided single structures. Two-lane twin strucures account for another 12.1 percent of the bridges. An average bridge in the POPULATION file has a length of 176 feet and a curb-to-curb width of 31 feet and an approach roadway width of 35.3 feet for a 51.3 percent shoulder reduction. The average bridge was built in 1954 with a remaining life of 25 years. It carries an ADT of 3,703 vehicles with a traffic mix of 11.2 percent trucks.

- Overall, 71.9 percent of single structures are narrow while that for twin structures is only 39 percent based on the narrowness definitions and assumptions used for the POPULATION file. Narrow bridges are more prevalent in rural than in urban areas and the percentage of narrow bridges decreases with higher functional class.

SAMPLE File

- An average two-lane undivided structure is 169 feet long, 27.7 feet wide with 11-foot lanes and approach roadway width of 29.8 feet. About half have approach guardrails. For two-lane divided structures, the average bridge is 245 feet long, 36.8 feet wide with 12-foot lanes and approach roadway width of 40 feet. Guardrails exist on almost all of the approaches to the bridges.

- ADT on undivided bridges is usually less than 1,000 vehicles per day. The majority of divided structures have ADT of more than 8,000 vehicles per day.

- Most bridges are straight and level, indicating the older practice of making grade changes on the approaches.

- As bridge length increases, the bridge width, the percentage of bridges with shoulder reduction, and the extent of the shoulder reduction increase. For undivided narrow bridges ($\leq$ 24 feet), most have no approach shoulders or large shoulder reductions. For divided structures with bridge widths above 36 feet, the percentage with no shoulder reduction increases drastically.

7.1.3 General Bridge Accident Characteristics

POPULATION File

- Single vehicle accidents are more frequent on rural bridges while multi-vehicle accidents are predominant on urban bridges. This may partially account for the significantly higher severity of accidents on rural bridges as compared to urban bridges (11.4% versus 5.8% K + A injuries).

- Single vehicle accidents are much more severe than multi-vehicle accidents with more than twice the percentage of fatal and incapacitating injuries (12.5% vs. 6.2%).

- Guardrail/median barrier and bridge rail are the most frequently struck objects in single vehicle accidents. Rear-end collisions are the most frequent for multi-vehicle accidents, followed by angle collisions and sideswipes in the same direction.

- Impacts involving bridge ends are by far the most severe (29.8% K + A injuries) while guardrail/median barrier collisions are the least severe (9.5% K + A injuries). By using proper approach guardrails and transition treatments, the severity of bridge end accidents may be significantly reduced to that of guardrail impacts.

- For multi-vehicle accidents, head-on and sideswipe-opposite direction collisions are the most severe (23.6% and 12.2% K + A injuries, respectively) while sideswipe-same direction and rear-end collisions are the least severe (3.0% and 4.2% K + A injuries, respectively).

- Single vehicle accidents are the predominant accident type for one-lane and two-lane single structures and for four-lane twin structures, while multi-vehicle accidents are the overwhelming majority on the other types of structures.

- Two-lane undivided single structures have significantly higher accident severity (11.4% K + A injuries) than the other structure types.

SAMPLE File

- Accident severity increases with greater values of bridge length, percent shoulder reduction, speed limit and BSI rating, but decreases with greater bridge width, higher level of roadside distraction, and increasing

ADT. However, the relationships are generally very weak except for roadside distraction.

- More collisions with another vehicle and less fixed object impacts occur on undivided bridges than on divided bridges. The percentage of collisions with another vehicle decreases and the percentage of fixed object impacts and rollovers increases with greater bridge width, less shoulder reduction, greater degree of curvature, level grade, reduced level of roadside distraction, presence of signing, delineator/object marker, and approach guardrail but no longitudinal marking, and, most importantly, lower ADT.

- The percentage of guardrail/median barrier impacts is lower and other fixed object impacts higher for undivided bridges than for divided bridges. This reflects the more extensive use of approach guardrail and median barrier and the lesser clutter of fixed objects with divided structures. The percentages of impacts with bridge rail and bridge end/abutment are slightly lower for undivided bridges. Also, the percentage of opposite direction conflicts seems to decrease with greater bridge width.

7.1.4 Specific Bridge Accident Characteristics

- The accident vehicles are fairly evenly distributed between mini/subcompact, compact, intermediate and full size vehicles with 71.8 percent of the vehicle curb weights between 3,000 to 4,000 pounds and another 20.1 percent less than 3,000 pounds. Surprisingly, there are no significant differences in resultant injury severity between the various vehicle sizes and weight ranges.

- The majority (61.6%) of the departure angles are 15 degrees or less with an average of 14.6 degrees and an average departure speed of 52.9 miles per hour. Over three-quarters of the vehicles are tracking or yawing at 30 degrees or less. The distance travelled from departure to first impact is usually very short with only 22.6 percent of the vehicles traveling more than 50 feet.

- Over three-quarters (77.4%) of the accidents involve more than one impact, half of which are three or more impacts. The injury severity of the accident increases with the total number of impacts from 14.3 percent AIS $\geq$ 2 for single impact accidents to 40.0 percent AIS $\geq$ 2 for accidents with four or more impacts. This clearly indicates the importance of subsequent impacts for accidents involving barriers.

- Over half (52.4%) of the first impacts occur in Approach 1 with 32.3 percent on the bridge itself and only 11.3 percent in Approach 2. The majority (56.5%) of the first impacts involve guardrails or median barriers with guardrail end or transition sections accounting for 12.9 percent. Bridge rail accounts for 25.8 percent of the first impacts with bridge rail/parapet end another 6.5 percent.

- For the first barrier impact, the average impact angle is 14.4 degrees and 87.1 percent of the impact angles are at 25 degrees or less. The average impact speed is 50.6 miles per hour with 73.1 percent of the impact speeds at 60 miles per hour or less. It appears that the impact conditions currently used in full-scale crash testing of longitudinal barriers, i.e., impact speed of 60 miles per hour and impact angles of 15 and 25 degrees, are good approximations of the average and limiting impact conditions. There is a weak trend indicating that higher impact speeds are associated with smaller impact angles. Also, 74 percent of the vehicles are either tracking or yawing at 30 degrees or less at impact.

- Velocity changes for the first barrier impacts are fairly low in relation to the impact speeds, indicating that the impacting vehicles retain a large proportion of their impact speeds after separating from the barriers. Subsequent impacts are of considerable importance.

- The impacting vehicle is redirected or comes to rest against the barrier in 73.1 percent of the first barrier impacts and the separation angle is usually very gentle. However, 22.7 percent of the impacts resulted in improper performance by the barrier, including overriding (10.1%), vaulting (8.4%), and penetration (4.2%).

- For the first barrier impact, higher injury severity is associated with increasing impact speed, but not with impact angle or velocity change. Also, injury severity is lower if the vehicle was redirected than if the vehicle overrode, vaulted or penetrated the barrier.

- For subsequent barrier impacts, the impact speeds are lower, but the impact angles are higher than the first barrier impacts. Also, the vehicles are more likely to be yawing and impacts with the sides or back of the vehicles are more frequent. This indicates that the vehicle trajectories for subsequent impacts are more abrupt although the impact speeds are lower.

- The first barrier impacts account for only 58.7 percent of the most severe impacts with subsequent barrier impacts another 21.3 percent, and the remaining 20 percent involve other objects or impact types.

- Rollovers and nonhorizontal impacts have the highest injury severity rate (47.8% AIS $\geq$ 3), followed by impacts with bridge rail/guardrail ends (41.7% AIS $\geq$ 3). As for barrier impacts, bridge rail impacts are slightly more severe than those with guardrails or median barriers.

- For the most severe impacts, higher injury severity is not associated with impact speed and only marginally with greater velocity change, indicating the predominance of the effects of impact type on injury severity.

7.1.5 Extent of Narrow Bridge Accident Problem

- Bridge-related fatal accident rates are significantly higher than average for all road types. Bridge-related non-fatal injury accident rates are also higher than average for interstates and rural arterials and collectors, but lower for urban arterials and collectors. It can be concluded that a safety problem does exist with bridges in general, particularly with interstates and rural highways.

- Accident frequencies are higher on urban bridges than on rural bridges due to higher traffic volume in urban areas. However, once traffic exposure is taken into account, the accident rates are higher on rural bridges than on urban bridges.

- Accident frequencies decline with lower highway types while accident rates increase, again reflecting the effect of traffic exposure. Interstate bridges have the highest accident frequencies but the lowest accident rates. Conversely, bridges on collectors have the lowest accident frequencies but the highest accident rates.

- Bridge narrowness, as defined in terms of shoulder reduction, has significant effects on accident rates for two-lane undivided single structures and four-lane twin structures and has marginally significant effects for four-lane undivided single structures and twin structures with more than four lanes. However, bridge narrowness has no significant effect on accident rates for one-lane bridges and all divided single structures.

- Shoulder reduction seems to have some effect on accident severity for twin structures, with higher accident severity for bridges with greater than 50 percent shoulder reduction, but lower for bridges with 1-50 percent shoulder reduction. However, bridge narrowness appears to have no effect on accident severity for all single structures with the exception of one-lane bridges, whose sample size is too small to attach much significance to the results.

7.1.6 Relationships Between Individual Bridge Characteristics and Accident Measures

- Bridges with accidents have much higher ADT, greater bridge length (especially for bridges with shoulder reduction or no approach shoulder), and, for undivided bridges, greater degree of curvature and shorter tangent distance than bridges with no accidents. However, bridge roadway widths are similar for bridges with or without accidents.

- The percentage of divided bridges with accidents is more than three times that of undivided bridges with much higher accident frequency. However, there is very little difference in accident rate, indicating the effect of higher traffic volumes on divided bridges. When only bridges with accidents are compared, the frequency is only slightly higher and the rate much lower for divided bridges. This reflects the higher percentage of accident bridges for the divided structures.

- The percentage of bridges with accidents increases with greater shoulder reduction and bridge widths.

- Accident frequencies increase with greater values of bridge length, bridge width, percent shoulder reduction, degree of curvature on the bridge and approaches, percent grade on the bridge, and ADT.

- Accident rates also increase with greater values of bridge length, percent shoulder reduction, degree of curvature on the bridge and approaches, and percent grade on the bridge, but are unaffected by bridge width. A weak relationship between accident rate and ADT suggests that the rate increases with higher ADT for undivided bridges but decreases for divided bridges.

- Accident frequencies and rates increase drastically with increasing degree of roadside distraction. Contrary to expectation, a strong trend also exists for higher frequencies and rates for bridges with warning and/or no passing signs, longitudinal marking, and delineator/object markers. The cause might be that such traffic control devices are installed at bridges with higher traffic volumes and/or with past accident experience.

- Accident frequencies and rates generally decrease with increasing Bridge Safety Index (BSI), but the relationships are weak, especially for undivided bridges.

- There is a general lack of strong relationships between accident severity and the various bridge and approach characteristics.

7.1.7 Statistical Relationships Between Bridge Characteristics and Accident Measures

- Results from the discriminant analyses indicate that bridges with accidents can reasonably be distinguished from bridges with no accidents based on certain bridge characteristics. However, attempts to distinguish bridges with (K + A) injuries to those without were met with little success and the summaries below only apply to the discriminant functions on accident frequencies. Breakdowns by urban/rural and narrow/non-narrow categorizations improve on the results of the discriminant analyses.

- For undivided bridges, the discriminant variables, in the order of descending importance, are ADT, roadside distraction, percent shoulder reduction, bridge degree of curvature, curb presence, bridge length, approach degree of curvature, and longitudinal marking. Increases in these variables increase the probability of accidents on such bridges.

- For divided bridges, the discriminant variables are ADT, roadside distraction, percent shoulder reduction, barrier rating, BSI, bridge percent grade, speed limit, and bridge length. Higher barrier rating and steeper grades decrease the probability of accidents on such bridges. Increases in the other six variables increase the probability.

- The major differences between the discriminant functions of urban and rural bridges reflect the increase of trucks in the traffic mix in urban areas, while roadside distraction has much less influence on accident occurrence on urban bridges. Also, for undivided bridges, the more frequent use of barriers in urban areas is manifested in the discriminant function.

- The key differences between the discriminant functions of narrow and non-narrow undivided bridges are bridge width and curb presence, which are more important for narrow bridges, while urban/rural and speed limit are more important for non-narrow bridges. For divided bridges, the differences between narrow and non-narrow bridges are more widespread with the key changes on percent truck in the traffic stream and bridge horizontal alignment for non-narrow divided bridges, displacing bridge length and curb presence for narrow divided bridges.

- Stepwise multiple linear regression analysis was conducted to relate bridge, approach, operational, and countermeasure characteristics to accident frequency, rate, severity, and cost measures for bridges with accidents. The regression results for accident frequency and rate are generally fair with about 25 percent of the sample variations explained. As for accident severity, the regression results are expectedly poor with R^2 values of under 10 percent in most cases. Breakdowns into urban/rural or narrow/non-narrow categorizations improve the regression results somewhat, but still explain less than half of the sample variations in most cases.

- For undivided bridges with accidents, accident frequency increases with higher ADT, steeper grade, and more roadside distraction, and decreases with greater BSI and longer sight distance. Accident rates decrease with increasing ADT, BSI, speed limit, roadside distraction, curb presence, bridge width, barrier rating, and longitudinal marking, and increase with greater bridge and approach degrees of curvature.

- For divided bridges with accidents, accident frequency increases with higher ADT, greater approach degree of curvature, and steeper bridge grade, and decreases with higher percent truck and speed limit. Accident rates are similar except that ADT has a negative coefficient and longitudinal marking presence, greater bridge width, and percent shoulder reduction increase the rate.

- Regression equations for the accident cost measures usually follow those of accident frequency and rate, but with slightly lower R^2 values. This reflects the general lack of relationships for accident severity which combines with accident frequency and rate to form the accident cost measures.

7.2 Discussions and Recommendations

This study has taken an in-depth look at the characteristics associated with accidents at bridge sites, including the extent of the problem, bridge site characteristics, bridge accident characteristics, and their relationships.

- Many of the problems encountered in this study are associated with the quality of available data. Most of the data bases are intended strictly for recordkeeping purposes, with little consideration given for data analysis requirements. The data files are usually not coordinated and require major efforts to merge them into a single data base. There have been significant improvements in this area over recent years, but much remains for improvement. One such area is the standardization of definitions and terms for the data items and is recommended as a topic for future research and implementation.

- The accuracy of accident locations is another area requiring improvements. This is particularly important for evaluation of roadway and roadside features that are relatively short in length. For example, the average length of a bridge is around 200 feet or 0.04 mile. With the accuracy of accident locations given at 0.1 mile, it is just not possible to accurately relate accidents to bridges. It is recommended that a more accurate means of locating accidents be devised to provide better association between accidents and roadway or roadside features under study.

- This study is limited to only bridges on State highway systems because bridges not on State highway systems do not have a location identification system sufficient for computerized matching of accidents to bridges. Yet many of the narrow and problem bridges are on local highways. This lack of a location identification system for local highways would severely limit any major efforts to study accident problems associated with local highways. A simple, inexpensive, and reasonably accurate location identification system is needed for local roadways and is recommended as another topic for future research and implementation.

- Bridge narrowness, as used in this study, has some definitional problems. First, a bridge with no approach shoulder would automatically be considered as non-narrow as long as it is wider than 18 feet for a one-lane bridge and 24 feet for a two-lane bridge. Secondly, a bridge with a two-foot shoulder would have no shoulder reduction for a two-foot approach shoulder, 50 percent reduction for a four-foot shoulder, and 75 percent reduction for an eight-foot shoulder. In short, there is no distinction between a narrow roadway and a narrow bridge with the definitions used in this study. It seems appropriate that the narrowness of the roadway be included as part of the definition for bridge narrowness. One possible approach is to use the State's current design standard as the baseline for determining the narrowness of the roadway and the bridge narrownes can then be determined accordingly.

- The study results provide some clear directions for identifying bridges that may potentially have an accident problem and thus are candidates for countermeasure applications:

    1. Even though a safety problem does exist with bridges in general, it is more prominent with interstates and rural

arterial highways and should thus receive the most attention.

2. Emphasis should be placed on two-lane undivided single structures which have the highest accident rate and severity. There is insufficient data to assess the accident problem associated with one-lane bridges. However, it seems intuitively that one-lane bridges would pose a safety problem and deserve further consideration.
3. Bridges with past accident experience and classified as accident bridges using the discriminant functions developed in this study should receive first priority in consideration for safety counteremasures. Bridges with no past accident experience but classified as accident bridges, or with past accident experience but classified as no accident bridges, should have second priority. Bridges with no past accident experience and classified as no accident bridges should receive the lowest priority and probably not even be considered.
4. Accident frequencies and rates, either actual or predicted using the regression equations developed in this study, may be used as a further screening tool to identify bridges with more severe accident problems. It should be emphasized, however, that the regression equations are not intended for predictive purposes, but rather as a means of comparison. Little significance should be attached to the absolute values of the predicted accident frequencies or rates for individual bridges.

- Two of the original objectives of the study were to evaluate the effectiveness of existing safety countermeasures applicable to the narrow bridge accident problem and to develop warrants for such safety countermeasures. However, despite extensive changes to the original study design and methodology, it was still not possible to evaluate the countermeasure effectiveness with data collected in the study. The biggest problem encountered was the inability to determine what and when countermeasures were implemented on the study bridges. The current study design was thus limited to strictly that of comparison, which is too weak for countermeasure effectiveness evaluation.

In today's world of dwindling resources and rapidly escalating costs, it is essential that safety improvements at bridge sites, especially those at narrow bridges, be based on cost-effective warrants in order to reap the most safety benefits with the limited resources available. It is therefore recommended that another research effort be directed to the evaluation of safety countermeasures at bridge sites and to the development of warrants for such safety countermeasures.

The before-after-with-control or comparison design is a much better approach for countermeasure effectiveness evaluation although it is faced with many of the same problems encountered in this study. The biggest problem, as stated above, is to determine what and when countermeasures are implemented. Obtaining a sufficient sample size for proper analysis is another major problem in light of the small number of accidents per year per bridge. There are also many threats to the validity of the evaluation inherent in the system, such as the way bridges are selected for safety treatment, inaccuracy and inconsistency of accident data, implementation of multiple treatments, other changes at a site, etc. Many of these problems can be overcome with a carefully designed, planned, and executed study.

- Even though detailed evaluation on the effectiveness of safety counteremasures was not attained in this study, some observations and suggestions may be gleaned from the study results regarding the safety countermeasures.

1. Countermeasures requiring major reconstructions, such as widening of bridges and realignment of approach roadway, are unlikely to be cost-effective on the sole basis of safety benefits, given the low number of accidents per year per bridge and the lack of strong relationships between accidents and any of the physical features at bridge sites.
2. In the event that a bridge and its approaches are going to be reconstructed for other reasons, such as structural deficiency, it is desirable to have the bridge built to a design standard equal to that of the approach roadway. There is no apparent need for the bridge design standard to be any higher. However, if it is necessary for the bridge to be built to a lower standard, it is suggested

that the bridge width be at least the lane widths plus two three-foot shoulders or less than 50 percent shoulder reduction, whichever is wider. For instance, for a two-lane bridge with 11-foot lanes and four-foot approach shoulders, the bridge width should at least be (2 x 11) + (2 x 3) = 28 feet (the alternative using 50% shoulder reduction is (2 x 11) + (2 x 4) x 50% = 26 feet which is less than 28 feet). It is also suggested that no curb be present on the bridge and approach guardrail with proper transition and tapering be installed. Extremely sharp curves or steep grades should be avoided, but gentle horizontal and vertical alignment should not present any problem.

3. Bridge rail/parapet end impacts are by far the most severe. Properly installed approach guardrail and transition will result in significant reduction in the accident severity and is highly recommended as a safety countermeasure. However, this may result in a slight increase in the accident frequency. Also, impacts with untreated guardrail end sections are very severe in nature and should thus be safety treated, such as the use of breakaway cable terminal (BCT).
4. The frequencies of impacts with bridge rails and approach guardrails or median barriers are nearly equal which suggests that barrier countermeasures should include combined retrofits of the bridge rail and guardrail systems.
5. Roadside distraction is strongly related to accident frequency, rate, and severity. It suggests that better land use control around bridge sites to minimize access points and potential conflicts may be an effective safety countermeasure.
6. The effectiveness of low-cost safety countermeasures by means of traffic control devices, such as signing, longitudinal marking, and delineator/object marker, cannot be evaluated in this study due to data unavailability and experimental design used. However, there are indications that such safety countermeasures are being used at bridges

with past accident experience and/or high accident potential.

- Some findings based on the 124 bridge accidents investigated in-depth are worthy of consideration in the design of improved longitudinal barrier systems.

1. Subsequent impacts are prevalent for barrier collisions at bridge sites. Post-impact trajectory of vehicles should be closely scrutinized for bridge rail and approach guardrail designs.
2. A quarter of the vehicles are yawing at greater than 30 degrees at impact. It is believed that vehicle yawing would have no adverse effect for impacts with normal bridge rail or guardrail sections. However, it could increase the severity of impacts with bridge rail/parapet and guardrail ends. Also, it could enhance the possibility of rollovers. It may be worthwhile to consider vehicle yawing as a parameter in the design of barrier systems.
3. A surprisingly high percentage of the impacts result in some form of improper barrier performance, i.e., overriding, vaulting, or penetration. Part of this may be attributed to the widespread use of turndown guardrail and treatment in the study area and perhaps improper barrier mounting height. A closer examination of this potential problem is recommended.

REFERENCES

1. "Accident Facts," yearly publications of the National Safety Council, Chicago, Illinois.

2. NHTSA compilation of Annual Accident Reports of 43 states, 1978.

3. "Fatal Accident Reporting System, 1978 Annual Report," NHTSA, U.S. Department of Transportation, Washington, D.C., 1979.

4. M. H. Hilton, "Some Case Studies of Highway Bridges Involved in Accidents,"Highway Research Record No. 432, Highway Research Board, Washington, D.C., 1973.

5. K. R. Agent, "Accidents Associated with Highway Bridges," Research Report No. 427, Kentucky Bureau of Highways, Lexington, Kentucky, May 1975.

6. Leon Nagin, "Economic Benefits of a Strong Bridge Program," Rural and Urban Roads, March 1978, page 42.

7. "NACo Survey Documents Off-System Bridge Problem," Rural and Urban Roads, September 1978, page 34.

8. FHWA, "Special Bridge Replacement Program," 5th Annual Report to Congress, Department of Transportation, Washington, D.C., December 1975, page 2.

9. D. L. Ivey, R. M. Olson, N. E. Walton, and G. D. Weaver, "Safety at Narrow Bridge Sites," presented at the 62nd Annual Meeting of AASHTO, Birmingham, Alabama, November 1976.

10. "Highway Safety, Design and Operations. Narrow Bridges - Driver Dilemas," Hearings before the Subcommittee on Investigations and Review of the Committee on Public Works, House of Representatives, Ninety-Third Congress, June 1973.

11. D. L. Ivey, R. M. Olson, and N. E. Walton, "Safety at Narrow Bridge Sites," Final Report, NCHRP Project 20-7, Task 7, September 1976.

12. W. P. Walker, "Influence of Bridge Widths on Transverse Positions of Vehicles," Proceedings of the Twenty-First Meeting of the Highway Research Board, December 1941.

13. B. F. Byrne, "Bridge Shoulder Width Study," Final Report No. W. Va. DOH36, Department of Civil Engineering, West Virginia University, Morgantown, West Virginia, February 1976.

14. R. R. Roberts, "The Effect of Bridge Shoulder Width on Traffic Operational Characteristics," presented at the 55th Annual Meeting of the Transportation Research Board, January 1976.

15. F. M. Council, D. W. Reinfurt, B. J. Campbell, F. L. Roediger, C. L. Carroll, A. K. Dutt, and J. R. Dunham, "Accident Research Manual, Report No. FHWA/RD-80/016, February 1980.

16. J. A. Cirillo, "Interstate System Accident Research - Study II," Highway Research Record No. 188, 1967, page 1.

17. T. M. Newton, "A Method of Field Evaluation of Narrow Bridges for Priority Indexing," Texas Transportation Institute Report No. FHWATX79-233-1, July 1979.

18. D. L. Wood, B. Bohuslav, and C. J. Keese, "Remedial Safety Treatment of Narrow Bridges," Traffic Engineering, Volume 46, No. 3, March 1976, page 11.

19. S. A. Smith, J. Purdy, H. W. McGee, D. W. Harwood, A. D. St. John, and J. C. Glennon, "Identification, Quantification, and Structuring of Two-Lane Rural Highway Safety Problems and Solutions," Interim Report, JHK and Associates, Alexandria, Virginia, August 1980.

20. D. S. Turner and N. J. Rowan, "An Investigation of Accidents on Alabama Bridges Approaches," presented at the 61st Annual Meeting of the Transportation Research Board, Washington, D.C., January 1982.

21. "Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems/1978," U.S. Department of Transportation, Federal Highway Administration, May 1980.