

1. Report No. FHWA/TX-05/0-4366-1		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle DEVELOPING AN IN-SERVICE PERFORMANCE EVALUATION (ISPE) FOR ROADSIDE SAFETY FEATURES IN TEXAS				5. Report Date December 2004	
				6. Performing Organization Code	
7. Author(s) Ida van Schalkwyk, Roger P. Bligh, Dean C. Alberson, D. Lance Bullard, Jr., Dominique Lord, and Shaw-Pin Miaou				8. Performing Organization Report No. Report 0-4366-1	
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. Project No. 0-4366	
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080				13. Type of Report and Period Covered Technical Report: September 2001 – August 2003	
				14. Sponsoring Agency Code	
15. Supplementary Notes Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration. Project Title: In-service Performance Evaluation of Roadside Safety Features url: http://tti.tamu.edu/documents/0-4366-1.pdf					
16. Abstract Current methodologies for the in-service performance evaluation (ISPE) of roadside safety features are not viable and practical for all state departments of transportation. The research team developed an ISPE process that is sensitive to the data and resource constraints of TxDOT. The following methodology was used to develop the TxDOT-ISPE process: identify the objectives of the ISPE, estimate expected extent of data collection, evaluate existing DOT procedures and organizational structure, identify features to be included in the ISPE, develop framework for an ideal ISPE, identify system constraints within the DOT, identify alternative methodologies and data sources for the ISPE, design a DOT-specific ISPE process, design and conduct a pilot test of the ISPE, evaluate the data collection methodology and data quality during the pilot test, and recommend an ISPE process for TxDOT. A two-phase ISPE process was developed and tested to meet the specific needs of TxDOT. In Phase I, the data collection form included basic information such as accident date, location, whether the vehicle rolled over or not, whether the crash was fatal or not, the specific device that was hit, and an evaluation of whether the system performed as intended or not. If the Phase I process identified a device having a high rate of failure, a Phase II investigation of that device was recommended. Phase II required detailed information regarding the layout and specific features of the particular device that was impacted, and a detailed investigation into the impact performance of the device. ISPE site inspection forms and training materials along with a recommended ISPE procedure were prepared as part of the project.					
17. Key Words In-Service Performance Evaluation, ISPE, safety, roadside safety features			18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov		
19. Security Classif.(of this report) Unclassified		20. Security Classif.(of this page) Unclassified		21. No. of Pages 228	22. Price

**DEVELOPING AN IN-SERVICE PERFORMANCE EVALUATION (ISPE)
FOR ROADSIDE SAFETY FEATURES IN TEXAS**

by

Ida van Schalkwyk
Assistant Research Scientist
Texas Transportation Institute

Roger P. Bligh
Associate Research Engineer
Texas Transportation Institute

Dean C. Alberson
Associate Research Engineer
Texas Transportation Institute

D. Lance Bullard, Jr.
Associate Research Engineer
Texas Transportation Institute

Dominique Lord
Associate Research Scientist
Texas Transportation Institute

and

Shaw-Pin Miaou
Research Scientist
Texas Transportation Institute

Report 0-4366-1
Project Number 0-4366-1
Project Title: In-Service Performance Evaluation of Roadside Safety Features

Sponsored by the
Texas Department of Transportation
In Cooperation with the
U.S. Department of Transportation Federal Highway Administration

December 2004

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas 77843-3135

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data, opinions, findings and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), Federal Highway Administration (FHWA), The Texas A&M University System, or the Texas Transportation Institute. This report does not constitute a standard, specification, or regulation. In addition, the above listed agencies assume no liability for its contents or use thereof. The researcher in charge of the project was Ida van Schalkwyk (M. Eng Transportation). The research team also included three registered engineers, Dean C. Alberson, Ph.D., P.E. 74891; D. Lance Bullard, P.E. 86872; Roger P. Bligh, P.E. 78550.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The research team thanks the TxDOT project director, Mr. Larry Buttler, P.E., for his assistance throughout the project.

The guidance of the project advisory committee is gratefully acknowledged and appreciated. The project advisory committee consisted of the following individuals: Mr. Mark A. Marek, P.E. (TxDOT Design Division), Mr. Bill Knowles, P.E. (TxDOT Research and Technology Implementation Office), Mr. Greg Brinkmeyer, P.E. (TxDOT Traffic Operations Division), and Mr. David Bartz, P.E. (FHWA).

Special acknowledgements are given to all TxDOT personnel involved in the project. This includes in particular all maintenance supervisors and maintenance personnel in the four maintenance units that participated in the pilot test:

- Central Houston Section, Houston District;
- San Antonio Metro Maintenance Section; San Antonio District;
- Fort Worth Central Maintenance Section, Fort Worth District; and
- Buffalo Maintenance Section, Bryan District.

It is their efforts that made this project possible. Other TxDOT personnel that participated in discussions and provided information regarding TxDOT procedures included Mr. Neal Munn and Ms. Kim Soucek.

The principal investigator of this project would also like to thank those that assisted her as part of the TTI research team: Dean C. Alberson, Ph.D., P.E., D. Lance Bullard, P.E., Roger P. Bligh Ph.D., P.E., , Dominique Lord, Ph.D., and Shaw-Pin Miaou, Ph.D.

TABLE OF CONTENTS

	Page
LIST OF FIGURES	xi
LIST OF TABLES	xii
CHAPTER 1: INTRODUCTION	1
PROBLEM STATEMENT	1
PROJECT OBJECTIVES	2
SIGNIFICANCE OF THE PROJECT	2
SCOPE OF THE PROJECT	3
Year 1	3
Year 2	4
ORGANIZATION OF THE REPORT	4
CHAPTER 2: STATE OF THE PRACTICE FOR ISPE	7
INTRODUCTION	7
NATIONAL AND STATE LEVEL INITIATIVES	8
The History of the ISPE Process	8
ISPE Projects in Texas	8
NCHRP 22-13 Database (5)	10
NCHRP 22-13 Pilot In-Service Evaluation (5)	11
Other Projects	11
CHAPTER 3: DEVELOPMENT OF THE TxDOT-ISPE PROCESS	15
INTRODUCTION	15
STEPS FOLLOWED IN THE DEVELOPMENT OF A TXDOT-ISPE PROCESS	15
IDENTIFYING THE OBJECTIVES OF THE ISPE PROCESS	17
IDENTIFYING SYSTEM CONSTRAINTS	17
ESTIMATING THE EXTENT OF DATA COLLECTION	
DURING THE ISPE PROCESS	19
Introduction	19
Frequency of Reported Impacts with Roadside Safety Features	20
Data Collection Forms	22
EVALUATION OF EXISTING TXDOT ORGANIZATIONAL STRUCTURE	
AND PROCEDURES	22
IDENTIFY THE ROADSIDE SAFETY FEATURES TO BE INCLUDED	
IN THE ISPE PROCESS	23
IDENTIFY POTENTIAL DATA SOURCES FOR THE ISPE PROCESS	24
Introduction	24
Accident Report Forms	25
Maintenance Reports	26
Site Inspections	27
Photographs	29

TABLE OF CONTENTS (CONTINUED)

	Page
Periodic Inspections and Unreported Crashes	29
Other Potential Sources of Information	30
FRAMEWORK FOR AN IDEAL TXDOT-ISPE PROCESS.....	31
IDENTIFICATION OF ALTERNATIVE METHODOLOGIES FOR THE TxDOT-ISPE PROCESS	33
Introduction.....	33
A Two-Phased Approach.....	33
Modified Procedure	34
TESTING THE TxDOT-ISPE PROCESS.....	34
CHAPTER 4: THE ISPE PILOT TEST	35
INTRODUCTION	35
PURPOSE OF THE PILOT TEST	35
PREPARATION FOR THE PILOT TEST.....	36
Introduction.....	36
Identify the Type of ISPE Process That Will Be Conducted in the Pilot Test	37
Identify the Devices That Will Be Included in the Pilot Test.....	37
Identify the Offices That Will Participate in the Pilot Test	37
Identify and Define the Data Collection Process That Will Be Followed.....	38
Identify the Data Management Process That Will Be Followed	40
Develop and Conduct the Training for the Pilot Test.....	41
EVALUATION OF THE PILOT TEST.....	42
ISPE Process	42
Data Collection Process	42
Data Sources	43
ISPE Site Inspection Forms	44
Maintenance Related Documentation.....	46
Photographs.....	47
Accident Reports.....	49
Data Management Process.....	49
Training.....	49
Other Issues.....	50
CHAPTER 5: ISPE DATA ANALYSIS AND STATISTICS	51
INTRODUCTION	51
IDENTIFICATION OF PROBLEMATIC FAILURE RATES.....	51
ANALYSIS OF SELECTED GROUP OF DEVICES	53
DATA COLLECTION EFFORT AND ANALYSIS IN PHASE II	54
COST-BENEFIT ANALYSIS AND ANALYSIS OF LIFE-CYCLE COSTS	55
Cost-Benefit Analysis	55
CONCLUSIONS.....	56

TABLE OF CONTENTS (CONTINUED)

	Page
CHAPTER 6: RECOMMENDATIONS FOR IN-SERVICE PERFORMANCE EVALUATION (ISPE) OF ROADSIDE SAFETY FEATURES	57
PHASE I ISPE	58
Identify Roadside Safety Devices.....	58
Select Participating Offices.....	58
Identify Personnel for Data Collection	59
Define Data Collection Process	60
Train Personnel	64
Collect Data	65
Analyze Data.....	67
PHASE II ISPE	69
Identify Roadside Safety Devices.....	70
Select Participating Offices.....	70
Identify Personnel for Data Collection	71
Define Data Collection Process	71
Train Personnel	72
Collect Data	73
Analyze Data.....	74
CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS.....	75
THE ISPE PROCESS RECOMMENDED TO TXDOT	75
THE ISPE DILEMMA	75
DEVELOPMENT OF AN ISPE PROCESS FOR TxDOT	76
BENEFITS OF AN ONGOING ISPE PROCESS AT A STATE DOT.....	76
ADDITIONAL BENEFITS OF AN ISPE PROCESS	77
REFERENCES	79
APPENDIX A: ANALYSIS OF IMPACTS WITH ROADSIDE SAFETY FEATURES IN TEXAS (TASK 3 OF PROJECT 0-4366).....	81
A1. INTRODUCTION	83
A2. THE DATA.....	84
A3. ANALYSIS OF THE CRASH DATA.....	85
A3.1 Characteristics of Crash Data Involving Roadside Safety Features	85
A3.2 Characteristics of Crash Data by Roadside Safety Features	96
A3.3 Characteristics of Crash Data by Vehicle Type.....	116
A4. SUMMARY AND CONCLUSIONS	123
APPENDIX B: ISPE SITE INSPECTION FORMS FOR PHASE I.....	125
APPENDIX C: ISPE SITE INSPECTION FORMS FOR PHASE II	131

TABLE OF CONTENTS (CONTINUED)

	Page
APPENDIX D: PRELIMINARY FINDINGS REGARDING SGT PERFORMANCE DURING PILOT TEST FOR TX 0-4366.....	137
D1. INTRODUCTION	139
D2. BACKGROUND	139
D3. ROADSIDE GEOMETRY	142
D4. EFFECT OF FLARE	143
D5. TENSIONING OF SGT ANCHORAGE.....	145
D6. BUCKLING OF THE EXTRUDER HEAD.....	146
D7. FAILURE OF SYSTEM COMPONENTS.....	147
D7. FAILURE OF SYSTEM COMPONENTS.....	148
D8. CONCLUSIONS AND RECOMMENDATIONS	149
 APPENDIX E: TRAINING MATERIALS FOR PHASE I – MICROSOFT POWERPOINT SLIDES	 151
 APPENDIX F: TRAINING MATERIALS FOR PHASE I – MANUAL.....	 175
 APPENDIX G: TRAINING MATERIALS FOR PHASE I AND II – PHOTOGRAPH POSITIONS AND ANGLES.....	 197
 APPENDIX H: TRAINING MATERIALS FOR PHASE II – MICROSOFT POWERPOINT SLIDES	 205

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Process Followed During the Development of an ISPE Process for TxDOT.....	16
2	The ISPE Process as Part of the Maintenance Process, the Safety Management Process of the Road Network and the Development of Safety Features Process	32
A1	Crashes Involving Roadside Safety Features by Year (1997-1999).....	86
A2	Number of Crashes by County (1997-1999).....	87
A3	Number of Crashes by Regional TxDOT District (1997-1999).	88
A4	Number of Crashes by Road Type (1997-1999).....	89
A5	Number of Crashes by Alignment Type.....	90
A6	Number of Crashes by Lighting Condition (1997-1999).....	91
A7	Number of Crashes by Day of the Week (1997-1999).	92
A8	Number of Vehicles in the Crash (1997-1999).....	93
A9	Relationship Between the Number of Crashes per Mile and Traffic Flow (1997-1999).	94
A10	Number of Crashes defined by the First Harmful Event for All and Single-Vehicle Crashes (1997-1999).....	95
A11	Number of Crashes by Roadside Feature (1997-1999).....	96
A12	Proportion of KAB Crashes by Roadside Feature.	97
A13	Number of Crashes Involving Highway Signs by County (1997-1999).....	98
A14	Number of Crashes Involving a Guardrail by County (1997-1999).....	100
A15	Number of Crashes Involving a Luminary Pole by County (1997-1999).	102
A16	Number of Crashes Involving a Mailbox by County (1997-1999).....	104
A17	Number of Crashes Involving a Median Barrier by County (1997-1999).....	106
A18	Number of Crashes Involving the End of a Bridge by County (1997-1999).....	108
A19	Number of Crashes Involving the Side of a Bridge by County (1997-1999).	110
A20	Number of Crashes Involving an Attenuation Device by County (1997-1999).	112
A21	Number of Crashes Involving a Concrete Barrier by County (1997-1999).....	114
A22	Number of Crashes by Vehicle Type for Each Feature (1997-1999).	117
A23	Number of Single-Vehicle Crashes Involving a Passenger Car by Severity (1997-1999).	119
A24	Number of Single-Vehicle Crashes Involving a Pickup Truck by Severity (1997-1999).	120
A25	Number of Single-Vehicle Crashes Involving an SUV by Severity (1997-1999).....	121
A26	Number of Single-Vehicle Crashes Involving a Large Truck by Severity (1997-1999).	122

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1 Selected Roadside Safety Features For Initial Scoping Process.....	20
2 Crashes By Severity (1997-1999).....	21
3 Number of Failures for Impact Attenuators.....	53
4 Number of Failures by Type of Device for Impact Attenuators.....	53
5 Investigation of Hydrocell Impact Attenuators.....	54
6 Estimated Time Required to Collect Phase I Crash Data.....	62
7 Number of Failures for Impact Attenuator Group.....	69
8 Number of Failures by Type of Impact Attenuators.....	69
A1 Selected Roadside Safety Features.....	85
A2 Crashes by Severity (1997-1999).....	86
A3 Number of Crashes by Time of Day (1997-1999).....	91
A4 Number of Crashes Involving Highway Signs by TxDOT Administrative District (1997-1999).....	99
A5 Number of Crashes Involving a Guardrail by TxDOT Administrative District (1997-1999).....	101
A6 Number of Crashes Involving a Luminary Pole by TxDOT Administrative District (1997-1999).....	103
A7 Number of Crashes Involving a Mailbox by TxDOT Administrative District (1997-1999).....	105
A8 Number of Crashes Involving a Median Barrier by TxDOT Administrative District (1997-1999).....	107
A9 Number of Crashes Involving the End of a Bridge by TxDOT Administrative District (1997-1999).....	109
A10 Number of Crashes Involving the Side of a Bridge by TxDOT Administrative District (1997-1999).....	111
A11 Number of Crashes Involving an Attenuation Device by TxDOT Administrative District (1997-1999).....	113
A12 Number of Crashes Involving a Concrete Barrier by TxDOT Administrative District (1997-1999).....	115
A13 Proportion of Crashes (percent) by Vehicle Type for Each Roadside Feature (1997-1999).....	118

CHAPTER 1: INTRODUCTION

PROBLEM STATEMENT

Several generations of roadside features have been developed to improve safety, but the effectiveness of these features in the field has not been fully investigated. While crashworthiness criteria have been updated in National Cooperative Highway Research Program (NCHRP) Report 350 to reflect the state of the art, the crash tests are based on idealized installations of features and limited impact conditions (*1*). In field installations, the roadside features may be located on a slope or curve, subject to the effects of environmental degradation, installed improperly, and maintained less often than prescribed. Also, in real-world crashes, vehicles can strike the safety features at angles, speeds, and orientations very differently from those used in the full-scale test procedures. Thus, the ultimate test of these safety features lies in their actual in-service performance in the field.

While there is a universal agreement in the roadside safety community on the importance of in-service evaluation for roadside features, many of the states, including Texas, currently do not maintain an inventory of roadside hardware and do not have a formal procedure to conduct in-service evaluations. Among the reasons cited by previous studies for states not having in-service evaluations include: (1) no “formal process” has been established to conduct the evaluation, (2) collecting and analyzing the data require a significant commitment of manpower, and (3) there is a lack of good, sustainable working relationships among police agencies, area engineers, and maintenance personnel.

Increased operating speeds and a changing vehicle fleet present an ongoing challenge to improving barrier design. The performance evaluation guidelines for guard fence, guard fence end treatments, and other highway safety appurtenances are set forth in NCHRP Report 350 (*1*). Although these guidelines represent the state-of-the-art in roadside safety, the design impact conditions are limited, and the tests are performed on idealized installations of barriers. In actual field installations, the barrier may be located on a slope, subjected to the effects of settlement, possibly installed improperly, and maintained less often than prescribed. Also, in the real world, vehicles can strike these barriers at different angles, speeds, and body positions than prescribed

in the crash test matrices. Thus, the effectiveness of design changes in the field is not always fully understood, and the ultimate test of a barrier lies in its actual in-service performance.

PROJECT OBJECTIVES

The objectives of this research are to:

- Establish practical procedures for gathering data on the in-service performance of roadside safety features for on-system highways,
- Develop a process for compiling, maintaining, and using in-service performance data to improve roadside safety; and
- Provide guidelines for implementation of the procedures and process. Results from NCHRP 22-13 and NCHRP 22-13(2) and other ongoing and previous national and state sponsored research should be investigated for their applicability toward developing in-service evaluation procedures for Texas (2).

SIGNIFICANCE OF THE PROJECT

Although remarkable progress has been made over the last 30 years in terms of mitigating the roadside safety problem, roadside crashes remain a serious problem. Each year, more than 14,000 persons are killed, and almost 1 million persons are injured in vehicle run-off-the-road accidents. These roadside crashes are estimated to cost society over \$80 billion per year. This figure is more than three times the amount federal, state, and local governments spend to maintain and operate roads each year.

The main purpose of the in-service performance evaluation (ISPE) of roadside safety features is to determine:

- How such devices perform under field conditions, including the vehicle crash experience involving the roadside feature
- Potential installation and maintenance problems, and
- The collision, installation and repair costs associated with the feature.

Knowing these performance measures will allow engineers, designers, and policy makers to maximize the safety benefit by installing the most appropriate roadside features in the needed locations and to identify potential design, installation, and maintenance problems in a proactive

and timely manner. Thus, ISPE provides a useful management tool that monitors roadside features to make sure the features are performing as intended in a consistent manner.

Another purpose of ISPE is to assess whether the vehicle crash performance in the real-world conditions is consistent with the expected performance as envisioned by full-scale crash test procedures, discussed in NCHRP Report 350. Therefore, ISPE can also be used to provide an independent check on crash test and evaluation procedures to ensure that crash test research efforts are indeed impacting the safety problems as expected. In this sense, ISPE provides an ultimate validation on the design of roadside features in actual service conditions, which is an integral part of the design process.

A third purpose of ISPE, which has not been stressed in the literature, is the potential of using the collision data obtained from the ISPE to modify or change the design for producing better and more cost-effective safety features. This function of ISPE helps to complete the safety feature production cycle, a process that is required in the production of medicines and most of the consumer products.

SCOPE OF THE PROJECT

The two-year project included the following tasks:

Year 1

- Conduct a critical review of recent and ongoing research pertaining to in-service evaluations of roadside safety features.
- Collect roadside features-related crash data and compile database.
- Conduct a statistical analysis on vehicle crashes involving roadside features on Texas on system Highways based on historical crash data.
- Review TxDOT maintenance procedures, tracking items (e.g., guardrail end treatment), and reporting data to identify and acquire useful sample information, including photos, for developing an in-service evaluation test plan.
- Develop a plan to conduct pilot in-service performance evaluations for a selected number of roadside safety features.
- Establish partnerships with, e.g., Department of Public Safety and TxDOT maintenance crews, to collect data.

Year 2

- Conduct pilot data collection.
- Analyze the collected data.
- Develop in-service performance evaluation procedures and guidelines.
- Document the research, findings, conclusions, and recommendations in a comprehensive research report.
- Prepare a project summary report.

The project is aimed at developing and testing an in-service performance evaluation (ISPE) process for use by the Texas Department of Transportation. The pilot test in the second year of the project is aimed at testing the methodology of the ISPE process as developed during the first year of the project. The research team and panel agreed beforehand, that data collected during the pilot test would not necessarily be suitable to make ISPE-related assessment with respect to certain roadside safety features. Researchers made this decision based on the premises that ISPE-related assessments would require a certain minimum sample size, and that conclusions about ISPE of particular roadside safety devices should only be based upon sound statistical principles.

ORGANIZATION OF THE REPORT

The report consists of seven chapters. The first chapter provides the scope and objective of the project. [Chapter 2](#) provides an overview of the State of the Practice for ISPE methodologies. [Chapter 3](#) provides a detailed description of the process followed to develop an ISPE process for TxDOT. [Chapter 4](#) discusses the pilot test of the ISPE process that was developed. It also describes the evaluation of the pilot test. [Chapter 5](#) covers data analysis and statistics related to the ISPE process, and [Chapter 6](#) provides the recommended ISPE process for TxDOT. [Chapter 7](#) provides the conclusions and recommendations of the project.

The report includes a number of attachments:

- [Appendix A](#): Analysis of Impacts with Roadside Safety Features In Texas
- [Appendix B](#): ISPE Site Inspection Forms for Phase I
- [Appendix C](#): ISPE Site Inspection Forms for Phase II

- [Appendix D](#): Preliminary Findings Regarding Single Guardrail Terminal Performance During Pilot Test For TX 0-4366
- [Appendix E1](#): Training Materials for Phase I – Microsoft Powerpoint Slides
- [Appendix F](#): Training Materials for Phase I – Manual
- [Appendix G](#): Training Materials for Phase I And II – Photograph Positions and Angles
- [Appendix H](#): Training Materials for Phase II – Microsoft PowerPoint Slides

CHAPTER 2: STATE OF THE PRACTICE FOR ISPE

INTRODUCTION

As early as 1971, research recommended in-service evaluation as an essential part of the roadside safety research and development cycle. NCHRP Report 118 recommended, “after the system has been carefully monitored and evaluated in service and its effectiveness has been established, the system is judged to be operational” (2). NCHRP Report 230 (3) recommended that formal in-service evaluations be routinely performed and NCHRP 350 re-emphasized the importance of in-service evaluation a decade later (1). Both reports recognized that without effective in-service evaluations it would be impossible to determine whether barriers developed and tested under laboratory conditions performed as expected in the field. Report 350 listed 13 objectives for an in-service evaluation, the first six of which were previously suggested in Report 230:

- 1) the actual field performance of the appurtenance,
- 2) unreported accidents,
- 3) the susceptibility to vandalism,
- 4) the effect of environmental factors,
- 5) influence of traffic conditions,
- 6) routine maintenance and repair costs,
- 7) a minimum project period of two years,
- 8) sufficient number of installations to result in a useful collection of cases,
- 9) frequent site visits,
- 10) before and after accident studies,
- 11) a method for observing unreported accidents,
- 12) maintenance and repair cost information, and
- 13) preparation and distribution of a final report summarizing the in-service evaluation.

NATIONAL AND STATE LEVEL INITIATIVES

The History of the ISPE Process

One of the earliest attempts to implement the in-service performance of traffic barriers was by Van Zwenden and Bryden in the State of New York (4). In a comprehensive project recently completed for NCHRP 22-13 researchers conducted a detailed survey and literature search to document past in-service performance evaluations and related collision studies, The report also methodically evaluated the procedures used in previous studies, including evaluation planning, data collection, and data analysis (5). In the context of the NCHRP Report 22-13, in-service evaluation implies that actual sites were visited and examined within a few days of a collision occurring. Sometimes reviews of collision and maintenance records have been referred to in the literature as in-service evaluations. It was suggested that, if these retroactive reviews are conducted without timely site visits, they be referred to as “collision studies.” In such cases, it is not always possible to directly observe the site and the device. For example, it is often very difficult to determine exactly what was struck if the only information available is the police collision report. Installation crews may not have installed the device correctly, it may have been damaged by a prior collision, or it may be an obsolete barrier the DOT no longer uses.

ISPE Projects in Texas

Two of the studies, which are contained in the NCHRP 22-13 in-service database, were performed in Texas and they are reviewed below. Note that in the first project, site visits were not performed, thus, they were considered a “collision project” by NCHRP 22-13 standards.

Turned-down End Treatments by Texas Transportation Institute (6, 7)

Initially, researchers intended to compare data from competing terminals (such as the Breakaway Cable Terminals) to the turned-down end. Due to the extensive use of the turned-down treatment and lack of competing terminals in the state of Texas, this goal was dropped. The objectives of the project then became to examine the frequency of vehicle overturn and accidental death or injury associated with turned-down end treatments.

The data collection for this project involved all accident data from the state of Texas for the year 1989. It appears as if the data came entirely from police accident reports. Using the accident data, researchers determined that, from a total of 190,512 accidents, 4,047 involved

guardrails. Once the researchers extracted accidents involving guardrails, a systematic four-step procedure was then followed to create the sample. The accidents involving guardrails, which resulted in fatalities, were initially filtered from the data. Next, every fourth non-fatal accident (based on accident number) was extracted resulting in a 25 percent sample of the non-fatal data set. The extracted fatal and non-fatal accident reports were then photocopied for use in the project.

The NCHRP 22-13 team commented that while this TTI analysis of the data is very thorough, the methods by which the data was collected introduce uncertainties in the conclusions drawn from the sample. However, the author is careful to mention possible discrepancies due to the method of data collection.

- Determination of guardrail/non-guardrail accidents and other classifications were based largely on the narratives contained within the police reports. The author was quick to admit the narratives in many cases were vague and unspecific. Therefore, accident classification in many cases was subject to misinterpretation.
- Data collection was retroactive in nature. The findings presented in this report are based on facts derived from the personal interpretations of the reporting officers at the site.
- Unreported accidents were ignored in the project. The author hypothesized that unreported accidents would create a lopsided view of the end hit to not end hit ratio. This assumption is due to the higher rate of accident severity associated with end terminals versus other points on the guardrail. Site visits were not incorporated in the project due to the retroactive nature of the data collection.

ET-2000 Study by FHWA, 1996 (8, 9)

Easton, in a 1996 paper, reported on an in-service performance of the ET 2000 guardrail end treatment in the state of Texas (8). The objective of this project was to determine the field performance of the ET-2000 and to refine the design to make the device safer and improve the ease of installation.

It is unclear from the report which agencies collected the data. However, the reader of the report may assume that police reports were utilized for data purposes based on the information

obtained for each accident and the references to eyewitness accounts of the accident. The researchers collected data through site visits and discussions with maintenance personnel.

The results of the Texas project are based on a period from April 1993 to some time during 1994 (date at which data collection ceased was not described). During this period, a total of 37 accidents involving ET-2000 were investigated. Of these 37 accidents, 92 percent resulted in no injuries or only minor injuries to the occupants. The three remaining A-level injuries involved a side impact, an unrestrained occupant in the bed of a pickup truck, and a possible misreported injury.

The Texas project of the ET-2000 served its purpose in the refinement of the terminal design. Here are some comments from the NCHRP 22-13 research team (6,7):

- The number of accidents in the Texas project was very small.
- It is possible that a few impacts may greatly change the results and therefore, the conclusions drawn from them.
- Road conditions and impact points of the vehicle were not accounted for in the Texas project. More side impacts could produce more incidents of more severe occupant injuries. Rainy conditions may create many more side impacts to the terminal.

No comparisons were made with other end treatment alternatives in the Texas project for similar traffic conditions to illustrate the significance of the findings.

NCHRP 22-13 Database (5)

As part of NCHRP Project 22-13, a database was developed that documents 49 previous in-service evaluation projects. The survey results indicated that 19 of the 45 states responding had performed some type of in-service evaluation in the past. Only 18 of the states had some type of roadside hardware inventory and the survey indicated that a few of the roadside hardware inventories were outdated. The survey also indicated that data sources used by respondents to perform roadside hardware evaluations in their states included police reports, hardware inventory, maintenance reports, or on-site investigations. Most of the respondents named police or maintenance reports as data sources with 21 and 20 responses, respectively. On-site investigations were used as data sources by 16 of the respondents and inventory reports by five of the respondents. The roadside devices studied by the respondents included various types of

end treatments, guardrails, median barriers, and impact attenuators. Furthermore, the most common problem reported by survey respondents and in the reports examined in the literature review was obtaining accident reports in a timely manner.

NCHRP 22-13 Pilot In-Service Evaluation (5)

As part of the NCHRP Project 22-13 researchers conducted a pilot in-service performance evaluation of guardrails, median barriers, and guardrail terminals, using data from portions of Connecticut, Iowa and North Carolina during a 24-month data collection effort from 1997 to 1999. They concluded that the pilot studies demonstrated that in-service performance evaluations could yield useful information about the field performance of roadside features. Performance data from these studies could be used to assess how effectively roadside safety resources were being used. If such information were available, decisions on upgrading roadside hardware, changing design standards, or developing new hardware could be based on observations made in the field rather than on intuition and judgment. The procedures and pilot studies also showed that it was possible to obtain useful data using relatively simple procedures and maintenance personnel.

Other Projects

Mak and Sicking recently completed a project aimed at the development of a continuous ISPE process for the Arizona Department of Transportation. In the State of Massachusetts and Washington, two other ISPE projects are currently under way (10).

Arizona Department of Transportation (10)

Arizona Department of Transportation (ADOT) funded the development of a continuous ISPE of highway safety features for ADOT. A report was released on the project, dated September 2002. During this study, researchers developed a four-subsystem ISPE process:

- *Level 1:* A continuous monitoring system as part of a Level 1 evaluation. In the Level 1 evaluation, a database is created by linking four computer databases currently in use by Arizona DOT: accident data, maintenance data, highway and traffic data, and the roadside feature inventory.
- *Level 2:* At Level 2, supplemental data is collected by:

- field data on the roadway, the roadside, and the selected roadside safety feature, and
 - a manual review of the hard copies of the accident report forms as completed by the police in an effort to obtain additional information not coded in the accident database.
- *Level 3:* An in-depth investigation takes place at Level 3 by conducting detailed studies of selected accidents to assess how the particular roadside safety feature performed.
 - *Level 4:* At Level 4, a new product evaluation subsystem is implemented. At this level, potential installation and maintenance-related problems associated with new roadside safety features are targeted.

As part of the project, a pilot Level 2 ISPE for cable systems was conducted. From November 22, 2001 to March 3, 2002, 28 cases were recorded.

ADOT has a number of available databases: the crash database, a maintenance database, a roadside feature inventory, and highway and traffic related data that can be linked. These data make a continuous ISPE process with an initial screening process, i.e., Level 1 as defined in the ADOT project, possible and sustainable. A roadside inventory also enables ADOT to assess the exposure of certain devices by linking it with highway and traffic data. The roadside inventory made the establishment of the distribution of different systems in a specific area relatively easily. It is important to note that the 28 reported ISPE cases in this project do not provide a large enough sample size to be representative of the population (refer to Chapter 5 for a discussion on statistical analysis of in-service performance evaluation data) and will therefore not allow the research team to make conclusions that are statistically significant regarding failure rates or any aspects related to the performance of the devices.

Washington State Department of Transportation: ISPE of Guardrail End Treatments and Pre-Cast Concrete Barriers (Ongoing)

In Washington State, the Washington State Department of Transportation (WSDOT) is currently completing an ISPE of guardrail end treatments and pre-cast concrete barriers. Approximately 802 miles of state-maintained highways are included in three contiguous WSDOT maintenance areas. A database is being developed as part of the project. The database consists of two linked files, namely, an inventory module with roadside inventory data for the

routes included in the project and an incident module that stores information related to impacts with the particular roadside safety device. Results of the project are not yet available.

Washington State Department of Transportation: In-Service Evaluation of Cable Systems (11)

WSDOT recently completed a preliminary in-service evaluation of 24.4 miles of cable systems installed on Interstate 5. The focus of the project centered on the costs related to the system and the before and after accident experience. The evaluation did not include ISPE site inspection forms as part of the process.

The process included an assessment of the maintenance experience with the cable systems. Researchers sent questionnaires to maintenance supervisors of each area, and they included comments from the maintenance areas in the ISPE report.

Worcester, MA: Impact Monitoring System Project (Ongoing) (12)

In this ISPE project, guardrail systems are equipped with a proprietary sensory device. This device monitors sensors that provide information regarding significant vibrations and also alerts the authority if the chain of sensors is broken as a result of an impact. Results of this project are not yet available.

CHAPTER 3: DEVELOPMENT OF THE TxDOT-ISPE PROCESS

INTRODUCTION

Performing an ISPE as part of the roadside safety process seems logical and simple but a multitude of factors influences the development of the ISPE process for a state DOT. Each State DOT differs in terms of available and maintained information sources, procedures within the road safety management process, organizational structure, and characteristics (e.g., size, geographic location, etc.). Although there is certainly common ground in terms of the objectives of the ISPE process, it is not possible to have a “one size fits all” methodology for all state departments of transportation. Failure to take system and budget constraints into account when developing and implementing an ISPE process will have a definite influence on the quality of data collected, the benefit the particular state DOT will obtain from the ISPE process, and the sustainability of the ISPE process.

The research team decided early on to develop an ISPE process that can fit into existing procedural and organizational procedures and functions. The motivation was that it would improve the likelihood of implementation, make that implementation within the state of Texas easier and more cost effective, and increase the likelihood of success and long-term sustainability of the TxDOT-ISPE process. Researchers identified and incorporated other system constraints into the development of alternative ISPE methodologies for a TxDOT-ISPE process.

STEPS FOLLOWED IN THE DEVELOPMENT OF A TXDOT-ISPE PROCESS

This chapter serves as a summary of the process that was followed to develop the ISPE process as recommended in [Chapter 5](#). The research team identified a typical process that can be utilized to develop an ISPE process for a state department of transportation. It is summarized in [Figure 1](#). This section discusses the various steps in the development process and incorporation of the TxDOT specific issues.

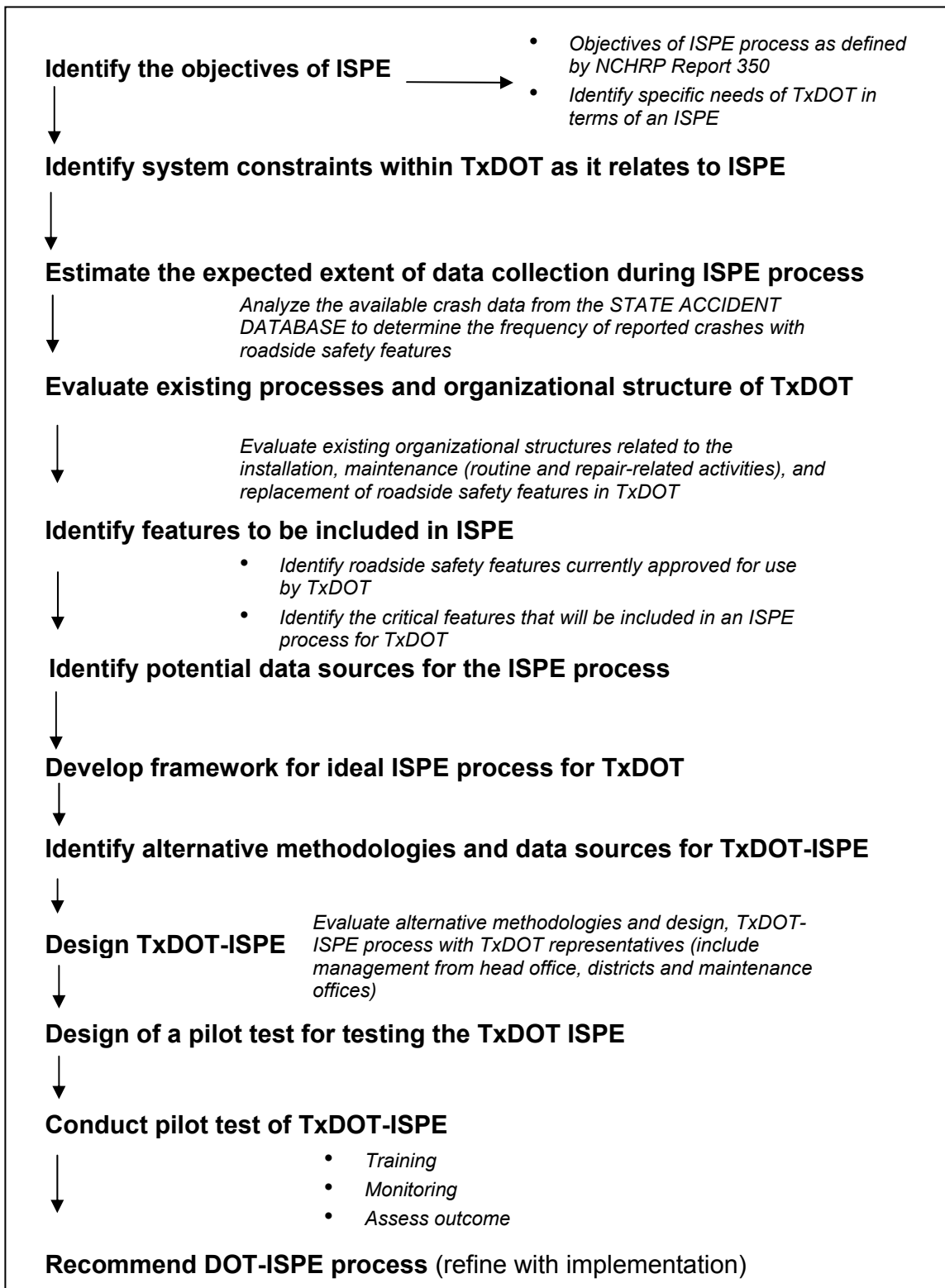


Figure 1. Process Followed During the Development of an ISPE Process for TxDOT.

IDENTIFYING THE OBJECTIVES OF THE ISPE PROCESS

An essential part of the methodology process is to first consider the objectives of an ISPE process. Apart from the objectives identified in NCHRP Report 350, TxDOT has their specific needs in terms of the ISPE process.

The objectives of the ISPE process as described in NCHRP Report 350 were listed in [Chapter 2](#). A review of current and proposed methodologies in conjunction with meetings with TxDOT design and maintenance personnel, led to the conclusion that existing procedures currently available did not provide a viable and practical ISPE process for TxDOT. Limited budgets (both on the operational and research level), the lack of a roadside hardware inventory, the inability to link the existing Maintenance Management Information System with the accident report database and large traveling distances within the state, among others, necessitated the development of a tailored TxDOT-ISPE process. TxDOT required a process that would be easy to implement, and put as little strain as possible on monetary and manpower resources while achieving the basic objectives set forth for ISPE. In other words, maximizing the benefit of an ISPE process while limiting the time and effort related to such a process (i.e., sensitive to the needs and constraints of TxDOT).

In order to achieve these goals, the researchers sought to develop a plan that enables a meaningful assessment of performance while minimizing resource requirements. Specific objectives included working within existing maintenance reporting procedures, limiting data collection to specific key variables related to the site, installation of the features, and performance of the features, and ensuring any recommended changes to current practice were reasonable, practical, and justified.

IDENTIFYING SYSTEM CONSTRAINTS

Several system constraints exist for conducting an ISPE for the State of Texas. This section lists and discusses these constraints. The research team and research panel identified the following major system constraints:

- TxDOT has a limited budget, both in terms of maintenance and research related activities.
- TxDOT has limited manpower to devote to an ISPE process and any related activities.

- Current TxDOT data information systems do not make provision for specific items that would be required to allow for the integration of the ISPE process related data. TxDOT representatives also noted that changes to these databases are not likely to be supported by the management of TxDOT.
- TxDOT does not have a roadside safety hardware inventory system, and it is unlikely that such a system will be available in the near future.
- The accident report and DPS database do not distinguish the specific type of roadside safety hardware used in a replacement or repair operation.
- Concerns were raised by the research panel regarding the accuracy and completeness of the TxDOT Maintenance Management Information System (MMIS).
- The Texas DPS accident database normally lags two years behind, and timely crash data is therefore not available unless it is coded directly from the accident report form as part of the ISPE process. This delay increases the amount of effort required to conduct an ISPE in Texas and also eliminates the opportunity to verify that at least the reported crashes are represented in the reported ISPE cases.
- The Texas DPS database only records the first harmful event. In the event that an impact with the roadside safety feature is not the first harmful event, this device will not be included in the report and even if it is the first harmful event, the specific device type (e.g., brand) is not part of the coded crash data. It is also not recorded on the accident report form. However, if the local maintenance office matches the accident report form, the crash data and particular device type can often be determined for the ISPE process.
- Traveling distances from a central location within the state of Texas are prohibitive given consideration of the expected frequency of impacts with roadside safety features across the state. This limitation influences decisions regarding the nature of site inspections after a device is impacted and before it is repaired or replaced.
- The research panel stressed that the amount of data collected by maintenance personnel had to be limited as much as possible to minimize the burden on the already extended maintenance offices.
- The research panel required that any ISPE data collection by maintenance personnel should not interfere with their day to day responsibilities and duties.

- A limited maintenance and research budget and recent reductions in the available funding to TxDOT requires that the TxDOT-ISPE process be as affordable as possible. Requirements on manpower and resources of TxDOT should be kept to a minimum.

As a result of the system constraints listed, researchers decided during the first year of the project that a two-phased approach to the ISPE process would be more appropriate than the detailed one-phase ISPE process utilized in the pilot test of NCHRP 22-13 and in the current ISPE that WSDOT is conducting on pre-cast concrete barriers and guardrail end treatments. The system constraints also influenced the approach followed during the development of an ISPE process for TxDOT. It also led to the preparation of alternative ISPE strategies for conducting an ISPE in Texas.

It is important to note that the system constraints identified are based on current operational and managerial approaches and practices within TxDOT. It is recognized that changes in these areas may affect the ISPE process. It is, therefore, recommended that the proposal of any future ISPE project to TxDOT includes a section that demonstrates consideration for any changes that may have taken place since this project was conducted. For example, the implementation of additional data elements into the MMIS and improvement in current accuracy as well as the ability to link ISPE data to timely accident data will lead to a significant simplification of the ISPE process.

ESTIMATING THE EXTENT OF DATA COLLECTION DURING THE ISPE PROCESS

Introduction

The extent of data collected during an ISPE process has a significant impact on the associated costs and benefits of an ISPE process. To enable the research team and panel to evaluate alternatives in the data collection process, the research team conducted a detailed analysis of impacts with roadside safety features based on reported crashes. The researchers developed Data collection forms and refined by determining the extent of data collected that is appropriate for TxDOT.

During the first two project meetings, the research panel stressed the fact that the ISPE process, the product of this project, should not require extensive data collection or large

databases. Focus of the research team had to be directed to simple and practical ways to obtain information while limiting time, effort, and other resources. Therefore, this report does not represent an ISPE project of all of the devices in use by TxDOT even though all the devices were included during the pilot test in the ISPE process development. This section discusses the estimation of the extent of data collection and levels of data collection that would be appropriate for TxDOT.

Frequency of Reported Impacts with Roadside Safety Features

A detailed analysis of reported roadside safety feature crashes was performed using the Texas Department of Public Safety (DPS) crash database for the years 1997 to 1999. This police-level database has a \$500 damage reporting threshold for property damage only (PDO) crashes. [Table 1](#) lists the different roadside safety features included in the analysis. [Table 2](#) summarizes the total number of crashes by severity in the state of Texas used for the initial scoping process for the ISPE. The database contains various codes for “object struck” that are pertinent to a roadside safety hardware including, but not limited to, highway signs, mailboxes, side of bridges, guardrails, median barriers, attenuation devices, luminaire poles, end of bridges, and concrete barriers. [Appendix A](#) provides a summary report of the analysis performed to determine the frequency of impacts with roadside safety features in Texas.

Table 1. Selected Roadside Safety Features For Initial Scoping Process.

Features	Features	Features
Highway Sign (20*)	Mailbox (31)	Side of Bridge (41)
Guardrail (23)	Median Barrier (39)	Attenuation Device (45)
Luminary Pole (29)	End of Bridge (40)	Concrete Barrier (56)
* Object code number on the DPS accident form		

Table 2. Crashes By Severity (1997-1999).

Severity	Roadside Safety Features	TxDOT Maintained Highway	State of Texas
Fatal	909	7,090	9,345
Injury A	3,990	32,162	52,223
Injury B	11,807	94,759	169,614
Injury C	17,250	209,926	389,201
PDO	27,348	169,558	305,422
Total	61,304	513,495	925,805

Ideally state departments of transportation, FHWA, roadside hardware manufacturers, and researchers involved in roadside safety design, implementation, and management would like to have a record of all hits to a particular system. This record should ideally include, for each hit, the specific impact conditions and crash characteristics such as vehicle type, location of impact, impact speed, impact angle, vehicle orientation, injury severity, and other crash-related information. Unfortunately, not all crashes are reported, and the extent of unreported crashes is largely unknown. Furthermore, the impact conditions associated with a crash are not available from police-level data and can be estimated only through a detailed clinical analysis and accident reconstruction. Accident reconstructions would require more detailed site inspections than is normally carried out during the completion of crash reports, and they add considerable time and cost to an ISPE process.

As shown in [Table 2](#), the annual average number of reported crashes with roadside safety devices in Texas is more than 20,000. This number is obviously too large to analyze in a clinical fashion for the purpose of determining impact conditions. Establishing a sampling scheme to reduce the number of cases to be investigated is complicated by the fact that TxDOT does not currently have a roadside feature inventory to facilitate such a process. Ideally a random sample should be selected from all the impacts but due to the fact that prior knowledge regarding impacts do not exist and that data should be collected from the impact site as soon as possible after the impact, such a sampling scheme is not practical or possible. An independent visit by members of the research team to all these sites is also neither practical nor affordable.

The research team identified alternative data collection methodologies that could be accomplished within the existing organizational structure and procedures of TxDOT as an alternative to the traditional approach of site inspections by the research team.

In the data collection process it is critical to obtain sample sizes large enough to represent the population that will enable the ISPE project to make statistically valid conclusions regarding aspects related to the performance and failure rates of a particular device. Chapter 5 discusses the sample sizes required to ensure statistically significant results in the ISPE data analysis process.

Data Collection Forms

An integral part of the ISPE process is the completion of data collection forms with specifics related to the ISPE objectives. The research panel clearly stated that extensive data collection forms, such as those utilized by WSDOT for their current ISPE of guardrail end treatments and pre-cast concrete barriers, and those utilized in the ISPE pilot studies for NCHRP 22-13 would not be acceptable to TxDOT. This objective had a significant impact on the development of the data collection forms and the extent of information gathered during the ISPE process.

The development of the data collection forms is described in further detail in the section titled Data Collection.

EVALUATION OF EXISTING TXDOT ORGANIZATIONAL STRUCTURE AND PROCEDURES

TxDOT currently performs maintenance activities of roadside safety features by TxDOT maintenance teams or through contractors. Once a feature has been impacted, personnel in the maintenance office with jurisdiction for the roadway are notified of the incident by the state, county, or municipal police department. The incident is logged into a daily diary, and an in-house accident information form is filled out. An inspector or maintenance foreman is then dispatched to the crash site to assess damage and estimate repair needs. A work order or statement of repair, which includes material quantities and cost estimates, is then prepared. This information is attached to the accident report, which is typically received within 1-2 weeks. The combined information is used for claim purposes to seek reimbursement for the repairs from the driver of the errant vehicle or their insurance company.

In the event of a crash resulting in a serious or fatal injury, both DPS and TxDOT prepare detailed reports on the incident. In addition to the general information collected at the less severe crashes, these reports contain photographs of the hardware, vehicle, and other physical evidence at the scene, and include an investigation of possible causative factors of the crash.

TxDOT sign crews repair and maintain sign supports. The daily schedule of the sign crew and route of repair are planned based on reported sign damage and other sign-related priorities. The time, equipment, and material needed for the repairs are typically tracked in a log.

From this background information, researchers recommended that the inspector or maintenance foreman that is dispatched to the crash site to assess repair needs and secure the site would be the appropriate person to complete the basic ISPE data collection form. Assessment by that individual would limit additional driving, and if a short data collection form can be developed, the information can be recorded in a relatively short period of time, on the crash site and in a relatively short time after the impact. It was also decided that it would be appropriate if this individual also took photographs of the damaged roadside safety feature, vehicle paths (if visible), and vehicles (if still present at the time of inspection). Taking photographs, their value and recommendations regarding photographs in the ISPE process is further discussed in the section dealing with data sources. The recommended ISPE process should also take the differences in operations between the signing crew and maintenance activities of the other roadside safety devices into account. Signing crews take care of the maintenance and replacement of signing on a route by route basis while maintenance activities of other roadside safety devices are either done by maintenance personnel or contractors on a case by case basis or after a specific number of devices in an area has been hit. The signing crews do not perform maintenance on other roadside safety devices and vice versa.

IDENTIFY THE ROADSIDE SAFETY FEATURES TO BE INCLUDED IN THE ISPE PROCESS

After consideration of these procedures, consultation with TxDOT personnel and the data analysis of statewide crash data, researchers decided that the TxDOT-ISPE process would focus on the following roadside safety features:

- sign supports,
- guardrails and transitions,
- guardrail end treatments, and
- impact attenuation devices or crash cushions.

Although the research panel and team agreed that bridge-railings would benefit from an ISPE, the research panel decided not to recommend their inclusion as part of the pilot test or the

development of the ISPE process for roadside safety devices in Texas. The decision of the research panel was based on the large variation of bridge-railings in use on the highway system in the state of Texas, the limited extent of damage normally sustained to bridge railings during impact, and the small likelihood of such crashes being reported to TxDOT maintenance offices.

The researchers prepared a list of all the approved devices in use within Texas for each of the four roadside safety feature groups listed above. The research team then identified critical elements for each device that can influence performance during an impact, including elements related to installation, maintenance, and repair. The research team also utilized the objectives of the ISPE process to identify any other ISPE-related issues for each approved device that should be incorporated in an ISPE methodology for Texas.

IDENTIFY POTENTIAL DATA SOURCES FOR THE ISPE PROCESS

Introduction

Typical data sources for an ISPE process include, but are not limited to:

- accident report forms (as completed by DPS),
- maintenance reports,
- site inspections,
- ISPE data collection forms,
- photographs, and
- periodic inspections to identify crashes that were not reported and did not result in any injuries or fatalities.

This section of the report describes each of these data sources and their relation to the ISPE process. Other potential data sources that can be utilized for the ISPE process are also included in the discussion. Recommendations by the researchers in terms of data sources to be included in the TxDOT-ISPE process were made based on the evaluation of the pilot test as described in [Chapter 4](#).

Accident Report Forms

Using the Texas DPS database seemed an obvious source of information for the TxDOT-ISPE. Unfortunately the current Texas DPS database presents the following problems in terms of integration with the ISPE process:

- The finalization for a particular year's data in the Texas DPS crash database typically lags two years and, therefore, does not provide timely data that can be matched in a timely manner with data collected in the ISPE process.
- Impacts with end treatments and transitions are not separated from guardrail in regard to the codes used for object struck in a crash. Further, the specific type of device within a particular hardware category (e.g., steel-post W-beam guardrail v. wood-post W-beam guardrail, or ET-2000 v. SKT) is not recorded as part of the accident data collection process.
- In the case of fatal crashes for which a more detailed report is prepared by the DPS, the photographs are not always adequate for identifying the impacted device.
- Crashes are classified by first harmful event and if a roadside safety device is impacted within the crash sequence, the device is not necessarily included in the Texas DPS crash database.
- The state of Texas does not have a roadside feature inventory. During the research project meeting, representatives from TxDOT stressed that any ISPE process developed for TxDOT should not require a roadside feature inventory. The research panel stressed that the development of a roadside inventory is not currently part of the goals of TxDOT.
- The time lag of the Texas DPS crash database combined with the absence of a roadside feature inventory presents significant limitations in terms of data analysis and interpretation.

Some of the local maintenance offices collect accident report forms primarily to assist with determination of fault and filing of claims related to the collection of repair costs. The accident report does contain information regarding the vehicle and other aspects of a crash that can provide value to an ISPE process. However, the report in itself does not provide any information regarding the status of the device, e.g. the device may not have been installed correctly, it may have been damaged by a prior collision, or it may be an obsolete barrier the

DOT no longer uses. According to the objectives for an ISPE, these elements are critical to the ISPE process. The researchers concluded therefore that the accident report is not sufficient as a primary source of information but that it should be included in the ISPE process as it provides valuable information to improve the understanding of the particular impact. This was demonstrated during the pilot study.

Maintenance Reports

The TxDOT Maintenance Management Information System (MMIS) is potentially a good data source for the TxDOT-ISPE process. Unfortunately, the researchers noted that many of the work codes and functions are somewhat categorical in nature and specific device types are not identifiable within the current MMIS database. The TxDOT representatives on the research panel pointed out that a number of operational problems make data from the current MMIS too unreliable for use in the TxDOT-ISPE process. It should be noted that the TxDOT representatives on the research panel reported that opportunity to modify the TxDOT-MMIS for purposes of collecting ISPE-related data. The researchers could therefore not include the capturing of ISPE data as part of the MMIS system into the TxDOT ISPE process. However, the research team is confident that future changes to this system may provide substantial benefits to the TxDOT-ISPE process.

As part of repair maintenance operations, the maintenance office prepares various maintenance-related information sheets that contain information that can add value to the ISPE process. Unfortunately, these information sheets are not standardized among maintenance offices in different districts and these differences creates some disparity in information that can complicate inter-district analyses. Nonetheless, it was decided that these forms could be a valuable data source in the TxDOT-ISPE process, and the inclusion of maintenance-related documentation sheets as a supplemental information source was recommended for Phase II in the pilot test. Evaluation of the pilot test process indicated that certain maintenance records are essential items in the ISPE process. [Chapter 4](#) discusses the use of maintenance reports as part of the information sources in the pilot test.

Site Inspections

Introduction

In all previous ISPE-related projects that were reviewed, including the proposed procedure by Mak and Sicking, site inspections are made by a member of the ISPE team after notification by either law enforcement agencies or maintenance personnel. According to Mak and Sicking the ISPE team consists of members of the research team or support personnel such as engineering students (10).

The geographic size of Texas makes it impractical for a centralized ISPE team to respond to incidents throughout the state. Assigning the task of site inspections to the inspector or maintenance foreman that already visits the site as part of his/her duties to inspect the damage to the roadside safety feature and complete repair forms appeared to be a viable alternative. The research team also agreed further that a site visit by an ISPE team member to visit sites of critical or unusual impacts during the detailed phase of an ISPE project would add substantial benefit to the process. This site visit enables the team member to make detailed notes of the impact and to follow up with further investigation where necessary.

Development of Site Inspection Forms

A list was prepared for each of the four roadside safety feature groups that were selected to form part of the TxDOT-ISPE process. For each of the devices, the research team identified:

- the critical elements that can influence performance during an impact, and
- specific elements related to installation, maintenance, and repair that can reduce the impact performance of the particular device.

Researchers evaluated and utilized these elements, and prepared a draft set of questions and a prototype data inspection form. The form is aimed at reporting on any of the approved devices within a selected category of roadside safety devices.

The research panel reviewed the prototype data inspection form. During meetings with the research panel, several issues were identified that required revision:

- Two separate data collection forms were needed: one for signing and another for the other device groups. Two forms are necessary to accommodate the different

procedures followed by the sign crew and the maintenance personnel involved with the maintenance of other roadside safety features.

- According to the TxDOT representatives, the prototype data collection form contained too much information and completion of the form required too much time, i.e., the amount of information required on the form had to be significantly reduced.
- The necessity of photographs of the damaged roadside safety feature was questioned but approved for the pilot study to enable the research team to assess the quality of the data collected.
- The research panel stressed the following:
 - The TxDOT-ISPE process should not require any modifications or adjustments to any existing TxDOT databases or software.
 - The ISPE process shall limit the amount of time and resources that TxDOT and DPS personnel have to spend collecting data.

Based on this feedback, the research team proposed an alternative strategy to resolve the limitations of this request. The implementation of a two-phased approach to the data collection during the ISPE process was recommended. During Phase I, the site inspection form will be limited to:

- basic questions to identify the particular device or device elements such as types of posts etc., and
- a data item that requires an assessment of whether the device performed as intended or not.

The research team agreed that a more detailed site inspection form will be utilized during Phase II that addresses some of the issues that were included in the prototype site inspection form. They also recommended that, in the case of critical or unusual impacts during a Phase II project, a member of the ISPE team should preferably also visit the site and supplement the ISPE Phase II data with further analysis results.

The research team noted that the more detailed Phase II data inspection form still contained less information than the prototype form based on the limitations set by the research panel. The research panel and research team agreed that the more detailed Phase II form will also provide a focused approach to the Phase II ISPE phase, a phase that will be more costly.

The Phase II data inspection form was transformed into two forms, one for signing and another for the other device categories (guardrails, end treatments, impact attenuation devices). These two forms accommodate the difference between operations related to the maintenance and repair of roadside safety features.

Photographs

During the initial planning and development process of the TxDOT ISPE process, photographs were not regarded as an essential information source for the process. Researchers elected to include photographs as an aid to facilitate evaluation of the quality of data collected at the site inspections for the pilot test, i.e., the maintenance personnel member conducting the site inspection was required to take photographs when he/she visits the site. These photographs can be taken in a relatively short period of time on the crash site, and due to the timely nature of these site inspections, in a relatively short time after the impact. Specific photographing procedures are:

- photograph the damaged roadside safety feature,
- photograph vehicle paths (if visible),
- photograph any vehicles at the crash scene (if still present at the time of inspection), and
- photograph any other aspect noticed at the site inspection that might provide additional information regarding the type of impact and the performance of the roadside safety features.

Taking photographs as part of the ISPE process will require training of personnel to ensure that the photographing procedures mentioned above are followed and included in each ISPE case file.

Periodic Inspections and Unreported Crashes

Visual inspections of impacts with roadside safety features are commonly used in other ISPE processes to supplement crash-and maintenance-related data collected for a particular device type. Unfortunately the absence of an inventory system of roadside safety features and the extensive traveling distances within Texas make frequent inspections impractical.

While there is merit in using such periodic inspections to help quantify unreported crashes for the purpose of accurately assessing the failure rate for a given safety device, the

researchers and research panel agreed that the benefits associated with these data within the ISPE framework should be balanced with the effort required to collect the information. For example, the periodic inspection of roadside safety features for purposes of quantifying impacts that do not require any form of repair maintenance may provide relatively small benefits compared to the cost associated with conducting periodic inspections at sufficient intervals. The research panel and researchers therefore decided that periodic inspections would not be cost-effective to include in the TxDOT ISPE process. The evaluation of the pilot test indicated that the absence of periodic inspections did not negatively impact the TxDOT ISPE process.

Other Potential Sources of Information

DPS notifies TxDOT districts of any fatal crashes within their jurisdiction. After such notification, the appropriate maintenance section prepares detailed documentation of these crashes that includes the DPS accident report, photographs of hardware, vehicle, tracks, etc., other forms (e.g., Form 17-91) and information, and an investigation into possible causative factors. DPS sent these detailed reports to Austin and a copy is kept at the District office. The research team recommends that such detailed reports be made available to researchers during an ISPE project. The research team should study these detailed reports of cases for a set period (such as three years) prior to the start of a Phase II ISPE project, so that these reports can be used as input during the planning for such an ISPE process.

In the event of changes to the existing MMIS system or the paperwork or processes followed during the maintenance of roadside safety features, the researchers recommend that TxDOT consider the inclusion of other information that is typically collected during the maintenance process. The additional information will improve the value of the ISPE process.

In some of the ISPE processes discussed in [Chapter 2](#), benefit-cost analyses are performed as part of the ISPE process, and traffic volumes are utilized as part of the process. Unless locations with specific similar geometric characteristics and similar traffic patterns are compared, it is not recommended that data from all locations where a similar device is installed are combined in a benefit-cost analysis, as this will not take exposure or specific geometric differences into consideration. Both exposure and differences in geometric design can introduce bias into the calculation process. This problem increases further when different devices are compared by increasing the potential for bias in the analysis.

FRAMEWORK FOR AN IDEAL TXDOT-ISPE PROCESS

Ideally the ISPE process should integrate the existing processes related to the repair or replacement of roadside safety features with existing information or data sources and systems.

Figure 2 shows the integration of these processes. It includes, among others:

- the Texas DPS database (accident database),
- the MMIS (Maintenance Management Information System),
- the roadside safety feature inventory system: geographic reference points with specific devices noted, ideally photographed to provide additional information regarding general site conditions,
- the road inventory system: provides detail regarding the facility on which the device is installed, including aspects such as traffic volume, number of lanes, roadside characteristics, shoulder-related information, design speed, 85th percentile speed, vehicle mix, etc.,
- a screening phase of the ISPE process to flag issues related to roadside safety features in use at a low cost with limited resources, and
- a more in-depth phase of the ISPE process to project the issues identified in the screening phase of the ISPE process.

The researchers pointed out that, with the integration of these systems, an initial screening phase of ISPE, i.e. a Phase I ISPE process, can be conducted to flag certain devices for further investigation by merging the different information systems. The concept behind a screening phase is to perform a low-cost assessment of the “failure” rate of a given device. They noted that, if the failure rate for a particular device is unusually high, it would be flagged for a more in-depth Phase II ISPE under which the nature and cause of the failures is investigated. Causes of the device failure may include, but are not limited to, one or more of the following factors:

- design deficiencies,
- improper installation and/or maintenance, and
- impacts that exceeds the design capacity of the device.

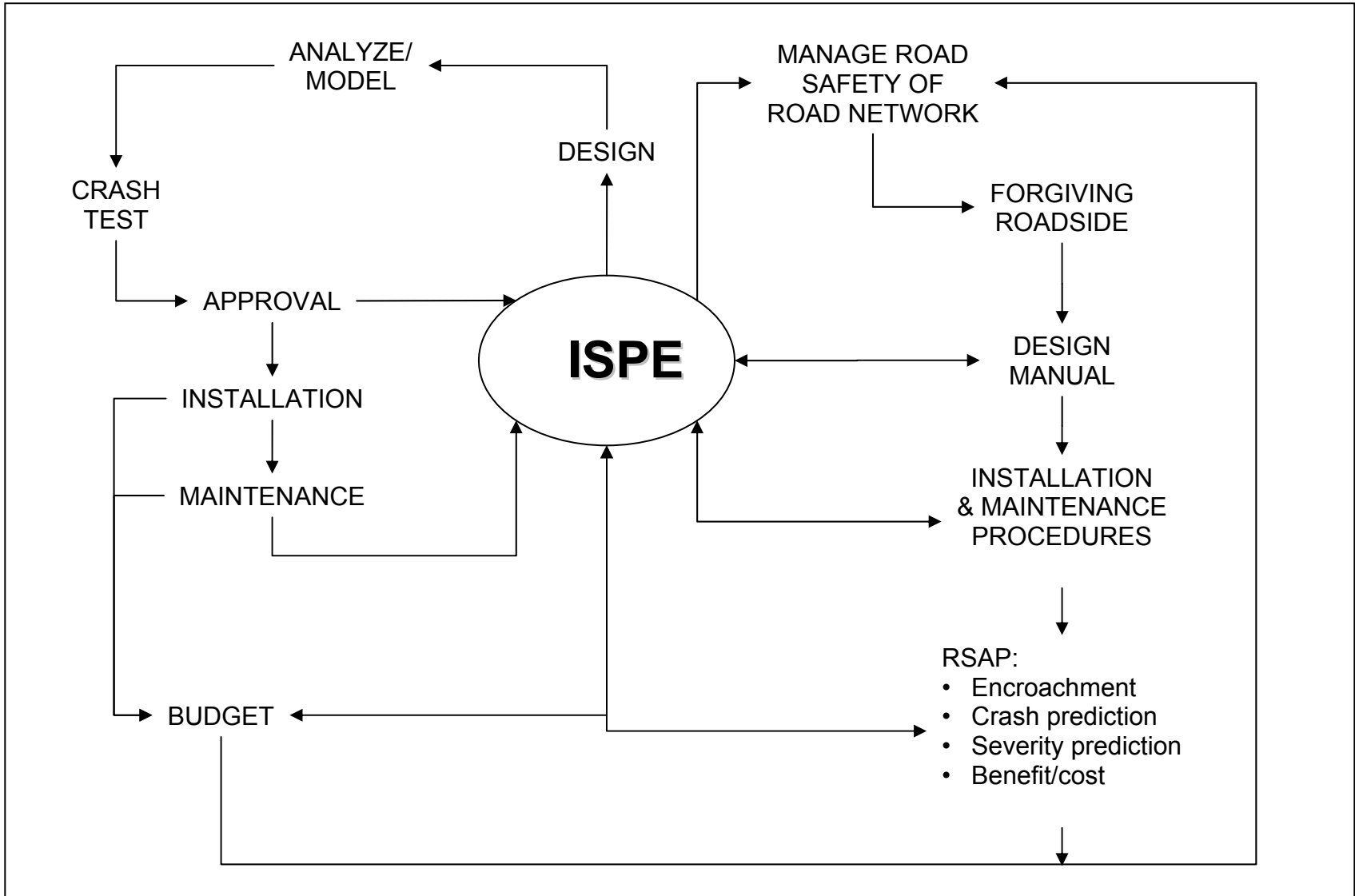


Figure 2: The ISPE Process as Part of the Maintenance Process, the Safety Management Process of the Road Network and the Development of Safety Features Process

IDENTIFICATION OF ALTERNATIVE METHODOLOGIES FOR THE TXDOT-ISPE PROCESS

Introduction

This section describes the alternative methodologies the research team identified during the ISPE process development. [Chapter 4](#) describes the pilot test that tested this methodology, and in [Chapter 6](#) provides the recommended ISPE procedure for TxDOT.

A Two-Phased Approach

During the developmental process, the research team prepared site inspection forms for each roadside safety feature included in the ISPE process. Based on feedback from the research panel (as discussed previously), the team then developed two sets of data collection forms, one for the signing crew and another set for use with the other roadside safety features. Phase I is a screening process that should preferably take place on a continuous basis and should ideally form part of the information collected for the MMIS system (and included in the data coded for the system).

In Phase I, the data collection form includes basic information such as accident date, location, whether the vehicle rolled over or not, whether the crash was fatal or not, the specific device that was hit, and an evaluation of whether the system performed as intended or not. If the Phase I process identified a device having a high rate of failure, a Phase II investigation of that device would then be recommended. The research team noted that Phase II will require more information regarding the layout and specific features of the particular device that was impacted, and will involve a more detailed investigation into the impact performance of the feature.

This two-phased approach enables the implementation of an initial screening process during Phase I, which would allow TxDOT to focus on specific device types or categories for a more detailed and labor intensive Phase II project.

Modified Procedure

Based on the framework for an ideal TxDOT-ISPE process and the above-referenced system constraints, the research team recommended the following approach:

- primary data collection will be done by the TxDOT maintenance personnel member that already visits the crash site to assess the damage to the roadside safety feature and determine repair requirements,
- data collection will be done through a Phase specific site inspection form and may be supplemented by photographs taken from specified locations (note the recommendation made regarding photographs in the ISPE process in [Chapter 6](#)), and
- at the local TxDOT office, maintenance material, cost and labor related paperwork will be attached to the site inspection form and the crash report form will be added as soon as it is received from the local police or DPS office.

TESTING THE TXDOT-ISPE PROCESS

The project proposal for this project identified a pilot test process as a measure to evaluate the ISPE process that was developed during this project. [Chapter 4](#) describes the pilot test process that was followed and also provides an evaluation of the pilot test. [Chapter 5](#) describes the ISPE data analysis process, and [Chapter 6](#) provides a detailed guideline to conduct a TxDOT-ISPE.

CHAPTER 4: THE ISPE PILOT TEST

INTRODUCTION

The researchers used a pilot test to test the prototype ISPE process that was developed in cooperation with the research panel and TxDOT personnel. Based on the changes that were made to the ideal ISPE process as described in [Chapter 3](#), the pilot test was conducted over a total period of six months. The pilot test took place in two phases, Phase I and II, utilizing the relevant site inspection form developed for the particular Phase and device category. The Phase I and II ISPE inspection forms are included in Appendix [B](#) and [C](#). As discussed in [Chapter 3](#), Phase I serves as a screening process where only the particular device is identified and where an assessment of whether the device performed as intended or not is recorded. Phase II is a more detailed stage and includes the assessment of various critical features of a particular device. Refer to [Chapter 3](#) for a detailed discussion on the development of a two-phased ISPE process and the development of the various site inspection forms used in the two phases.

This section describes the purpose of the pilot test and the preparation that was done before the pilot test, discusses the pilot test, and then concludes with a description of the evaluation of the pilot test process. The researchers incorporated the findings from this evaluation process to prepare [Chapter 6](#), the ISPE Guideline for TxDOT.

PURPOSE OF THE PILOT TEST

As part of testing the ISPE process, the pilot test included the following:

- developing of an ISPE process for TxDOT,
- identifying the critical elements related to a TxDOT ISPE process,
- determining the extent of data that can be collected within the restraints specified by the research panel and by the TxDOT system,
- evaluating the various elements in the ISPE process in terms of practicality and usability,
- evaluating the various approaches to the ISPE process,
- evaluating the pilot training materials used to train the TxDOT maintenance personnel participating in the pilot test,

- evaluating the ability of TxDOT maintenance personnel to collect data at various levels of detail, and
- evaluating the benefit of including digital photographs as part of the ISPE process.

The researchers noted that the sample size of the data obtained in the pilot test was not sufficient to make statistically significant calculations. [Chapter 5](#) discusses the recommendations made by the research team regarding the sample sizes that should be obtained to ensure statistically significant results. [Appendix D](#) provides preliminary findings regarding SGT devices currently in use by TxDOT. It was a product of both findings during the pilot test and from feedback provided by individuals that were involved in the pilot test process.

The pilot project was vital in terms of identifying critical issues related to the ISPE methodology but it also served as a testing ground to evaluate perceptions regarding:

- the ability of maintenance personnel to collect data,
- the value of certain data to be collected, and
- the extent of effort required during the IPSE processes.

The pilot study also served as a tool to identify differences between the participating offices that may impact the ISPE process.

PREPARATION FOR THE PILOT TEST

Introduction

Prior to the start of the project, the researchers clarified several aspects of the pilot test. Careful consideration was also given to aspects within the prototype ISPE process that had to be tested. The aspects that received particular attention before the start of the pilot test included:

- Identify the type of ISPE process that will be utilized to perform the pilot test.
- Identify the devices that will be included in the pilot test.
- Identify the offices that will participate in the pilot test.
- Identify and define the data collection process that will be followed.
- Identify the data management process that will be followed.
- Plan, prepare, and conduct the training of personnel that will participate in the data collection process.

These planning and preparation steps for the pilot test are discussed in more detail in this subsection.

Identify the Type of ISPE Process That Will Be Conducted in the Pilot Test

The research panel and research team decided that the pilot test would provide an excellent opportunity to evaluate the two-phased process as discussed in [Chapter 3](#). Phase I took place from November to January and Phase II from February to April.

Identify the Devices That Will Be Included in the Pilot Test

As discussed previously, the research team identified various device types and specific devices per category that could be included in the ISPE process. The research panel reduced this list and the site inspection forms covered all of these devices. It was decided that all the devices selected would be included in the pilot test to enable the research team to evaluate the various items within the site inspection forms.

Identify the Offices That Will Participate in the Pilot Test

Mr. Larry Buttler from the Maintenance Division of TxDOT played a major role in identifying the local maintenance offices that took part in the pilot test. Mr. Buttler and the research team then made a selection of participating local maintenance offices from a group of offices that volunteered to participate in the pilot test. The research team also used selection criteria that included the maximization of the expected number of impacts that can be reported in the total six-month pilot test period and also the inclusion of urban and rural areas.

The following local maintenance offices participated in the pilot phase of the project:

- Central Houston Section, Houston District;
- San Antonio Metro Maintenance Section; San Antonio District;
- Fort Worth Central Maintenance Section, Fort Worth District; and
- Buffalo Maintenance Section, Bryan District.

The Buffalo Maintenance Section participated in Phase I of the project but due to the low levels of incidents to report, the area was excluded from Phase II. The Central Houston Section also did not collect any signing ISPE data because this area already experienced high volumes of incidents with the other devices included in the ISPE pilot test.

Identify and Define the Data Collection Process That Will Be Followed

Introduction

During the development of the prototype ISPE process, as discussed in Chapter 3, the research panel raised several concerns regarding the data collection process. Besides the prototype site inspection forms, the research panel agreed with the research team that matching photographs with accident report forms would be beneficial to the process and would improve the understanding of what happened during the impact to the particular device. The research team proposed the inclusion of photographs to assist the evaluation of the completion of the data collection forms. The research team also decided the data collection in Phase II should also include any related maintenance documents prepared as part of the regular maintenance procedures. This section describes various aspects of the planning process followed for the data collection process. It also includes a description of the concerns the research panel voiced prior to the data collection process.

Concerns regarding the data collection process

Researchers used the pilot test to test the site inspection forms and to investigate the following concerns the research panel raised before the pilot test started:

- The Phase I data inspection form would require a certain level of skill and knowledge, both in terms of identifying the device correctly and in terms of judging whether the system performed or not. It was also unclear whether the existing level of expertise or the pilot test training would be sufficient to allow maintenance personnel to report these items correctly.
- The Phase II data inspection forms with reduced information items would not contain sufficient information for an ISPE process.
- The Phase II data inspection form required too many items to be completed at the site inspection, and that maintenance personnel are not likely be cooperative due to the additional work required for data collection during the Phase II ISPE process.
- The Phase II would require a certain level of skill and knowledge, both in terms of identifying the device correctly and in terms of judging whether the system performed or not. It was unclear whether the existing level of expertise or the pilot

test training would be sufficient to allow maintenance personnel to report these items correctly.

Process of data collection and monitoring

Maintenance personnel perform site inspections before impact related maintenance work is done. The research team recommended that the site inspection forms can be completed by the official while he/she is visiting the site as part of his/her daily task, i.e. simultaneously with the site inspections that are carried out as part of TxDOT procedure.

During Phase I, the site inspection forms were stapled together with the accident report form, if such a report was available. San Antonio Central Office, however, decided to prepare ISPE case files for each device that was visited for site inspections after an impact. This change proved to be an improvement on the initial approach. This approach was further refined by the research team and the researchers prepared Phase II ISPE case files for all the offices participating in Phase II. The ISPE case files included a site inspection form and a pocket for digital storage media for the digital version of the photographs taken during the site inspection. On the cover of the file, provision was made for the date of the impact, date of the site inspection, claim reference number, and the person that collected the data. A file number was also assigned to each file, distinguishing between the different offices and the particular phase of the process. Researchers can then use these numbers to identify the case file as a unique record in an ISPE-related database.

Data collection forms and the use of ISPE Case Study files

Testing the site inspection forms for the various devices included in the TxDOT-ISPE process was deemed essential. Besides testing the items the maintenance personnel were completing for each device, it also provided an opportunity to assess the validity of concerns expressed by the research team and research panel (as listed previously).

The researchers decided to include photographs as a required data collection item to allow the research team to assess the accuracy with which maintenance personnel completed the site inspection forms. The importance of using photographs and the associated value thereof are included in the section discussing the evaluation of the data collection process during the pilot test.

Identify the Data Management Process That Will Be Followed

The data management process for the pilot test included two major tasks, managing the data and monitoring the data collection process.

Managing the data

The research team and research panel agreed at the beginning of the project that, for the purpose of the pilot test, unless the pilot test provides large enough sample sizes to identify statically significant results, an analysis of the data collected during the pilot test will not be included. This important decision was made because the project was aimed at developing a process rather than performing an ISPE project for all the devices that TxDOT currently approves for use in the state, i.e., not to conduct an actual ISPE on all the devices currently in use. The researchers used a database to track the ISPE case files. The database file included information from each case file and some basic elements of the information provided for the ISPE process. This database is not included as part of this report due to the limited sample sizes of data collected during the pilot study process.

Recommendations by the research team regarding the data management process for an ISPE process or project are provided in [Chapter 6](#).

Monitoring the data collection process

After the first month of the pilot test, Ida van Schalkwyk, a member of the research team, visited each participating office. Although the maintenance offices were invited to contact any members of the research team during the ISPE process, she found at the first visit that in-person visits would be more appropriate as personnel felt more comfortable sharing their concerns and giving feedback in person (it seemed like they were reluctant to phone the research team with questions). The research team decided to conduct monthly visits to the offices. It also provided the research team with the opportunity to monitor the progress of data collection and to identify any issues related to the data collection process early on in the project rather than after completion of the pilot test.

The researchers tested both Phase I and II during the pilot test and no changes were made to the particular site inspection related questions that were included in the site inspection forms.

Develop and Conduct the Training for the Pilot Test

Dean Alberson and Ida van Schalkwyk, two of the research team members, conducted the training for Phase I at all the participating offices. The training session took three hours and included two breaks. The training sessions were also attended by some of the local area engineers and managers as well as other maintenance personnel identified by the management of the particular office. All the individuals that took part in the pilot test attended the training sessions. Ida van Schalkwyk conducted the training for Phase II at each of the participating offices and training took approximately two hours.

Purpose of the Training

The purpose of the training was to prepare the maintenance personnel to complete the site inspection forms. This included the following:

- discussing all the devices that were included in the ISPE process as developed in this project,
- discussing the activation mechanism of each of these devices along with typical failures,
- discussing elements in the installation, routine and repair maintenance that can influence the ability of a particular system to perform as intended, i.e., to reduce injuries,
- discussing each of the elements of the ISPE site inspection forms, taking photographs, and other issues critical to a successful ISPE process, and
- providing the opportunity for officials to ask questions regarding any of the systems currently used by TxDOT.

Training Material

The trainers used electronic slides with examples, both in diagrammatic and photographic format, to conduct the training. Each of the attendees received a copy of the slides and also an ISPE device manual prepared for the pilot test. The training material is included in Appendices E to H. Note that two different sessions were held for Phases I and II and the material is organized accordingly (Appendices E and F for Phase I and [Appendix H](#) for Phase II) .

EVALUATION OF THE PILOT TEST

ISPE Process

Two-phased approach

The pilot test indicated that the two-phased process is successful in terms of:

- providing an initial screening process through Phase I to identify devices that may warrant further investigation, and
- providing a more labor intensive but thorough investigation through Phase II that would enable TxDOT to identify specific problems in the in-service performance of particular roadside safety devices.

Data Collection Process

Process of data collection and monitoring

The research panel and research team decided that the maintenance personnel performing site inspections after a crash would be asked to complete the ISPE site inspection forms for the particular device that was impacted.

During Phase I the site inspection forms were stapled together with the accident report form if such a report was available. For Phase II the research team provided ISPE case files with the site inspection forms and a pocket for digital storage media with the associated photographs taken at the site. On the cover of the file, provision was made for the date of the impact, date of the site inspection, claim reference number, and the first and last name of the individual completing the ISPE site inspection form. A file number was also assigned to each file, distinguishing between the different offices and the phase of the process.

The provision of ISPE case files to the participating offices was welcomed by the maintenance personnel and proved to be successful in facilitating the inclusion of all the maintenance-related paperwork. Unfortunately the pockets for digital storage media with the associated photographs were not utilized as expected. This practice is essential to enable the users of the case files to accurately match the associated photographs. The San Antonio Central Office included grayscale printouts of the photographs in the files. This provided material for an easy review of the case file while the photographs in electronic format allows for easy inclusion

in high quality format in reports, in databases and for archiving (i.e. further evaluation at a later stage).

The data monitoring process, i.e., monthly visits by a member of the research team, proved beneficial in a number of ways. While it provided an opportunity for the maintenance personnel to provide feedback and ask questions regarding the ISPE data collection process (as they seemed reluctant to phone the research team to ask questions) and the various devices in use on the TxDOT roadway network, it also provided the opportunity for the research team to build relationships with the maintenance personnel. These relationships facilitated the flow of information that was necessary to make the data collection process a success. It also provided a sense of importance to the maintenance personnel – they were not collecting this data on their own but were supported by the research team. Since this process does not add a significant cost element to the project, this approach is strongly recommended.

Data Sources

The collection of site inspection data (with the ISPE site inspection form), maintenance-related documentation, site photographs, and an accident report form proved to be the best sources of information for the TxDOT-ISPE process. These data sources do not only increase the understanding of the extent of the impact, the extent of the damage to the system, and the performance of the system, but they also act as a control of similar information provided in one or more of the data sources. Feedback from the participating offices indicated that this requirement does not require extensive effort. It should, however, be noted that the assistance of the administrative personnel working with the maintenance-related information and the collection of accident report forms is critical to the success of the process. Prior to the implementation of an ISPE process or project, the research team should meet with the involved personnel to ensure that they have an appreciation of their critical role in the process. During this meeting and during the ISPE process, these officials should have the opportunity to ask the researchers questions about the ISPE process.

During the pilot test, the following data were collected:

- the ISPE site inspection form for the applicable ISPE Phase (Phase I or II),
- related maintenance documentation,
- associated accident report (whenever available), and

- site photographs.

ISPE Site Inspection Forms

Testing the ISPE site inspection forms for all the selected devices was also necessary to allow the research team to assess the validity of the concerns raised by the research team and research panel. During the first three months, the pilot test tested the Phase I and II site inspection forms that were prepared earlier on in the research project.

Prior to the pilot test the research team and panel noted several concerns regarding the data collection process. The following provides the list of concerns and the results from the evaluation of the pilot test process for each concern:

- *“That the Phase I data inspection form would require a certain level of skill and knowledge, both in terms of identifying the device correctly and in terms of judging whether the system performed or not and that it was unclear whether the existing level of expertise or the pilot test training would be sufficient to allow maintenance personnel to report these items correctly.”* Assessment of the completed site inspection forms and ISPE case files indicated that the maintenance personnel that completed these documents had sufficient skill and knowledge to identify whether a system performed as intended or not. The research team believes that the training process provided this knowledge and the issues covered during the training process for an ISPE process/project is therefore critical. In cases where assessment of whether a system performed or not was problematic, the additional information (if available) such as photographs, the accident report form and notes made by the maintenance personnel provided extra material for the researchers to assess. This was, however problematic in some cases due to the complexity of the crash or other factors. It is therefore strongly recommended that, in an ISPE process, the maintenance personnel be utilized to record the ISPE cases but in cases where the impact resulted in serious injuries or fatalities or where the assessment of whether a system performed as intended is questionable, a member of the research team should visit the site before the system is repaired. This approach is further discussed in [Chapter 6](#).

- *“That the Phase II data inspection form required too many items to be completed at the site inspection and that maintenance personnel are not likely to be cooperative due to the additional work required for data collection during the Phase II ISPE process.”* During the Phase II ISPE pilot test the maintenance personnel cooperated in the process and successfully participated in the process.
- *“That the Phase II would require a certain level of skill and knowledge, both in terms of identifying the device correctly and in terms of judging whether the system performed or not and that it was unclear whether the existing level of expertise or the pilot test training would be sufficient to allow maintenance personnel to report these items correctly.”* The training provided prior to the Phase I and Phase II pilot test provided the personnel with adequate knowledge to successfully complete the site inspection form. In cases where the assessment of the device performance was problematic, the research team generally observed that the particular case would have benefited greatly from a site inspection by a member of the research team.

The maintenance personnel completed the ISPE site inspection forms with varying degrees of success. The following items were cause for concern and should receive special attention during any training process and should be carefully monitored during any ISPE process:

- Dating the site inspection form. Although the crash date for a particular impact is not necessarily known, the date on which the site inspection was carried out is known. This date is important to ensure that the ISPE case file is assigned to a particular month. It is understood that the assignment might be in a month later than when the impact actually occurred. In the case where the accident report form later becomes available and is included in the ISPE case study file, the date assignment is updated.
- Providing an adequate and unique location description. Location descriptions were unreadable in some cases and in several cases did not allow for the identification of a unique location on the highway network. The inclusion of maintenance records as part of the ISPE case study file did improve the identification of the particular site but only if this item is recorded accurately. As recommended in [Chapter 6](#), the ISPE process for any device should include an assessment of performance at sites with

similar geometric and/or traffic conditions and therefore requires that the locations recorded as part of the ISPE process be captured accurately.

Identification of the different devices within the device type category was relatively accurate, and the provision of site photographs provided adequate information to correctly identify the device.

Maintenance Related Documentation

In the pilot test of Phase II, the participating offices were requested to collect the maintenance-related documentation for each ISPE case. This documentation was included in the ISPE case study file for each case. This approach enables the ISPE project to link maintenance-related information, i.e., cost, effort, materials etc. – important elements in the data analysis process, particularly for the calculation of benefit-cost ratios and assessment of life cycle costs. It is important to note that the use of this information should be utilized with great care to ensure that the information is not biased. This approach is discussed in further detail in [Chapter 5: ISPE Data Analysis and Statistics](#). It also provided a control for the location information provided on the site inspection form.

Although there is standard maintenance-related documentation that is used by all the maintenance offices, there were differences in some of the documentation provided in the ISPE case study files. The maintenance documentation, however, does not include the vehicle-related costs for the maintenance activities. It is important to ensure that all the maintenance-related costs and exposure rates be included as part of the ISPE documentation to allow accurate cost estimations if TxDOT desires to perform cost-related calculations. Cost-related calculations are further discussed in [Chapter 5](#) as part of the section describing ISPE data analysis. Note that the installation costs and the costs associated with routine maintenance are included in the ISPE case study files and should therefore be collected should TxDOT wish to perform these calculation. There is currently no mechanism that would allow for the collection of the installation and routine maintenance data to include in the ISPE process. It will require a roadside inventory database and an information system that captures both installation and routine maintenance by location and device. As noted before, TxDOT does not plan to develop a roadside inventory or an information system that would capture these cost items.

Photographs

Value of photographs

It was decided to include photographs as a required data collection item to allow the research team to assess the accuracy with which maintenance personnel completed the site inspection forms. However, during the pilot test process and the assessment of the ISPE case study files, the research team found that the photographs provided valuable information to assist in the assessment of the probable impact conditions, a critical element of the ISPE process.

The benefits of the site photographs include, but are not limited to:

- visual assessment of the impact damage to the system,
- impacting vehicle paths if visible,
- close-up detail of damage to specific elements of the device that was impacted,
- geometric characteristics of the installation, and
- improve the understanding of complex crashes (accident reports are generally written accounts of the crash as described by vehicle occupants and/or witnesses and site photographs complement the accident report information).

Added benefit of having a digital camera available

During the pilot test, the maintenance personnel noted that the availability of a digital camera in their vehicle allowed them to also take photographs of other incidents or aspects such as impacts with bridge structures. In this case the local maintenance office was able to email the photographs of the damage to the district office for review. This approach can possibly reduce the time and expenses related to initial site inspections.

Organization of digital photographs for the ISPE process

The organization of the digital photographs that were taken during the site visits was problematic in some cases, for example: some offices saved photographs of several different sites visited over different time periods on the same disk, and these disks were not labeled in terms of location or site inspection date. Although the properties of the digital photographs include a time and date it becomes problematic when more than one official visits different sites in one given day.

In an effort to improve the organization of the digital photographs, the research team provided ISPE case study files for the pilot test of Phase II with a pocket for digital storage media with the site photographs.

Unfortunately these pockets were not utilized as desired. It is essential to include the digital storage media with the printed digital photographs in the ISPE case study file because it is critical that the researchers/consultants conducting the ISPE process or project accurately match the associated photographs. The San Antonio Central Office included grayscale letter size printouts of the photographs and included that in the ISPE case study files. This was an improvement on the approach and allowed for easy review of the case file while the photographs are available in electronic format to allow for inclusion in reports, in databases and for archiving for further evaluation by the research/consultant team at a later date.

The researchers do not recommend the use of standard film photographs for the ISPE process because inclusion of the photograph into reports will require the scanning of the original photograph which normally do not render the same quality of digital image as obtained through the use of a digital camera. There is also a delay in the development of standard photographs, and a series of films will contain various different site inspection photographs – increasing the difficulty in the archival process of the photographs.

In the event that TxDOT decides to create an ISPE database, the digital photographs can be included into the database. Archiving of photographs should include at least the following information for each photograph:

- crash location
- date of impact (at least the month but the full date if available – this may be updated once the accident report form is received)
- date of site inspection
- device impacted

By archiving the digital photographs in this way, the photographs can easily be matched with the information collected in the ISPE case study files.

Photograph angles and positions

The trainers discussed the recommended photograph positions and angles during the training process for the pilot test. However, few of the site photographs that were taken as part of

the ISPE data collection process conformed to the recommended positions and angles. Fortunately the site photographs normally included photographs of the impacted device and vehicle paths, two critical items in the photographic data collection process. It is recommended that an on-site session be included during the training process to demonstrate the photograph angles and positions along with the reasons for the need of each of the photographs. During the monthly visits by a member of the research team, the photographs collected as part of the ISPE process should be evaluated to ensure that these requirements are met.

Accident Reports

Accident reports are critical in the ISPE process. They provide detail regarding the crash, impact, and injury severity. Ideally, the accident report should be matched with the ISPE site inspection forms. It is understood that not all the ISPE case study files will contain an accident report as some property-damage-only crashes may not be reported because no injuries resulted from the impact, while repair of the system was still required. The process of conducting periodic inspections to estimate property damage only crashes is not recommended because it is labor intensive and not very accurate since the inspector has no definite way to assess whether visible damage was the result of a particular crash and focuses limited resources on crashes resulting in damage to the system that do not require repair maintenance.

Data Management Process

Evaluation of the use of ISPE case study files showed that this approach is beneficial as it provides a paper record of the ISPE data and other data items collected for a particular impact. These case study files can be stored and accessed in the future if other studies are conducted. Should TxDOT decide to capture the data in a database, it will make capturing easier as it provides all the related information in one location. Monitoring the data collection process is also easier with all the information combined in one file.

Training

Training formed an important part of the ISPE process. The training not only provided the opportunity to instruct participants in the completion of the site inspection forms but also facilitated the training of maintenance personnel in terms of:

- critical elements within each device that can influence the ability of the particular device to fail during impact or reduce the ability of the device to reduce the severity of injuries,
- the manner in which each device performs during impact to reduce the severity of injury, and
- critical elements impacted by installation and maintenance (both routine and crash related) that can reduce the ability of the device to perform as intended.

The researchers found that the training proved to be successful in more than one way. While training was provided for the completion of the ISPE site inspection forms, the personnel met some of the members of the research team. It also led to an increased awareness of roadside safety devices, and the impact that installation and maintenance can have on the ability of the particular device to perform as intended. It also highlighted the importance of correct installation and maintenance activities and showed how these activities can reduce or affect the ability of roadside safety devices utilized by TxDOT to reduce injuries. The San Antonio Central Office reported that it increased awareness regarding the importance of maintenance in the ability of roadside safety devices in use by TxDOT.

Other Issues

Initially the research team and panel were concerned that the extra effort required implementing the ISPE process would be met with negativity at the participating maintenance office. Experience during the pilot test indicated otherwise. The officials participating in the ISPE pilot test were positive, eager to learn, and dedicated in the performance of their tasks.

CHAPTER 5: ISPE DATA ANALYSIS AND STATISTICS

INTRODUCTION

This section describes the characteristics of the sampling procedure for collecting and analyzing crash data as part of an in-service evaluation project. A sufficiently large number of crashes (or hits) must be collected in order to perform adequate statistical analyses and to determine whether certain groups of roadside devices (guardrails, end treatments, impact attenuators, and signs) perform as intended in the field. It also describes other data analyses that can be included as part of the ISPE process, such as benefit-cost ratios, before and after studies and average installation and maintenance expenditures.

IDENTIFICATION OF PROBLEMATIC FAILURE RATES

Before implementing an in-service evaluation project, it is important for the investigator to determine that the size of the sample is large enough to accurately determine if a certain group of roadside devices does not work as intended. In other words, the sample size should be large enough to properly detect if potential problems exist with the devices. Traditionally, the sample size is determined by various components. They include the power of the project, i.e., the probability of detecting a statistically significant association of a particular magnitude; the characteristics of the population (e.g., standard deviation), and the level of accuracy (e.g., 95 percent percentile) sought by the investigator.

The minimum required sample for Phase I will be determined by the failure rate under investigation. The question “Did the system perform as intended?” should be used to this effect. The following thresholds provide the minimum number of crashes for the given group of devices (note: the same numbers could be used for each type of device or for each district, etc.):

- failure rate of 10 percent: 410 crashes (or hits), and
- failure rate of 5 percent: 1,150 crashes (or hits)

The smaller the failure rate, the larger the required number of crashes. The numbers above were estimated for a project with a power of 80 percent and a significance level (α) of 5 percent. Alternative sample size can be computed given the characteristics described above with the following equation:

$$n = \frac{15.698 \times \bar{p} \times (1 - \bar{p})}{d^2}$$

where,

$$d = \bar{p} - 1\%$$

$$\bar{p} = (\text{failure rate in \%} + 1\%)/2$$

As an example, a group of devices did not perform as intended if the device failed in more than 42 of the 420 reported crashes recorded for the selected group. Obviously, any values above a failure rate of 10 percent in this example would warrant further investigation.

The sample scheme should include crashes occurring throughout the various TxDOT districts to cover all types of conditions: different roadway environments, weather patterns, terrains, use of devices in certain districts, and driver behavior among others. The project period should cover one full calendar year to account for the variations described above. In order to minimize biases introduced in the data collection effort, it is suggested to avoid collecting data only during specific time periods (e.g., Fall, etc.) or in only specific locations (e.g., Houston). In short, the proposed sampling scheme will facilitate the identification process for determining if specific problems occur in different districts or time periods.

The method proposed above does not include a measure to consider the severity of crashes. It is therefore suggested to monitor fatal crashes as a function of whether or not a type of device worked as intended. For instance, further investigation should be instigated if a specific type of device is associated with fatal crashes (e.g., the given type of device did not work as intended in 5 fatal crashes).

Note that the identification of the devices in Phase I could be done for the type of devices on an individual basis (e.g., Hydrocell®, Energy Absorption Systems, Inc. for impact attenuators) if enough observations exist. Similarly, the identification could also be done per district using the same principles above, as long as enough data is available. The geometric design of each of the locations where the device is used and was impacted should also be considered.

At the end of the data collection effort in Phase I, the failure rate should be computed for each group or type of devices. In the event the failure rate is above the pre-determined threshold

(5 percent, 10 percent, etc.), further analysis should be performed with the data collected in Phase I.

ANALYSIS OF SELECTED GROUP OF DEVICES

All the information collected from the forms in Phase I for a group of devices flagged as not working as intended should be collected. More specifically, the analysis should focus on the recorded sheet where the device did not work as intended. To do so, it is suggested to cross-tabulate (in single and 2x2 tables) the variables for each type of device. The analysis should also be separated by various districts for determining if problematic devices are localized or spread-out throughout the state. Variables that share common characteristics will warrant further investigation in Phase II. Tables 1 and 2 show an example of tabulated results for impact attenuators as detailed in the forms for Phase I (see other examples in the other section on the results for the Phase I project). In this example, a failure rate of 40 percent should warrant an investigation.

Table 3. Number of Failures for Impact Attenuators.

Worked as Intended?	Number
Yes	20
No	8

Table 4. Number of Failures by Type of Device for Impact Attenuators*.

Type of Device	Number of Failures
QuadGuard® (Energy Absorption Systems, Inc)	0
GREAT® (Energy Absorption Systems, Inc)	1
TRACC (Trinity Industries)	0
React 350® (Energy Absorption Systems, Inc)	0
Hexfoam® (Energy Absorption Systems, Inc)	6
Hydrocell® (Energy Absorption Systems, Inc)	1
TX Barrels® (TxDOT non-proprietary)	0
Total	8

Note: Use this approach for each variable from the form used for Phase I.

DATA COLLECTION EFFORT AND ANALYSIS IN PHASE II

Once the common variable(s) is (are) identified as being problematic, the data collection effort for Phase II should be initiated. This should be done only if the data provided in Phase I do provide a clear cut answer about the potential problems with the selected group, type, or location of devices.

The data collection effort will be governed by the variables identified in Phase I. For instance, if problems were identified with the Hydrocell system (as shown in the example above), special attention should be given for this type of device. In Phase II, there is no clear cut answer about the required sample size, given the fact the sample size will be governed by the selected variables. However, it is suggested to use the number of observations presented for Phase I. The equation provided for Phase I could also be used for determining the sample size. For instance, if a specific type of device in Phase I fails 40 percent of the time, the required sample size would be 13 for Phase II. A similar approach should be used for other variables (e.g., concrete versus dirt for foundation).

The analysis of the data for Phase II should follow a similar approach to the one proposed in Phase I. This means that the exploratory analysis of the data should be achieved through single and 2x2 tables. Variables with common characteristics should be investigated. Given the variables collected in Phase II, specific types of failures will help guide the investigator about whether the failure is caused by maintenance, design, or installation problems.

To continue with the example above, a new set of collected data for Hydrocell impact attenuators may give the characteristics shown in [Table 3](#). In this example, the components do not seem to remain attached in the event of a collision.

Table 5. Investigation of Hydrocell Impact Attenuators.

All components remained attached?	Shielding of Device?		
	Yes	No	Total
Yes	2	2	4
No	7	2	9
Total	9	4	13

COST-BENEFIT ANALYSIS AND ANALYSIS OF LIFE-CYCLE COSTS

Cost-Benefit Analysis

During a cost-benefit analysis, the costs and benefits related to a particular device are calculated. Costs typically include the fixed and operational expenditures such as installation and maintenance while the benefits normally refer to the reduction in the severity of injuries and the reduction in fatalities.

Any analysis such as cost-benefit ratios and before-and-after studies should be performed with great care to ensure that the analysis is not biased and presents valid results.

Bias in analysis

Within the ISPE process, TxDOT has the ability to focus on a particular device in an ISPE project or to select groups of devices within a device type such as crash cushions or end treatments. This selection process will greatly influence the design of the analysis process.

Where an analysis is performed on a device installed on different types of highway facilities (urban, rural), under different traffic conditions (low traffic volumes, high traffic volumes, lengthy peak hours, short peak hours, etc.), and different locations with different geometric characteristics, bias is inherent unless the analysis is performed on subsets of the ISPE data that will compare devices installed on similar facilities and in locations with similar geometric characteristics and under similar traffic conditions. For example, end treatments installed on straight sections of four-lane highways can not be compared to those installed at or close to gore exit areas. It is also important to take into consideration that the traffic volume of a facility in itself does not necessarily provide an indication of the probability of impacts and the associated characteristics of these impacts. For example, at high traffic volumes, operating speeds are generally low and although exposure is high, low-severity crashes are generally expected while low traffic volumes at night time are generally associated with high impact speed and high severity crashes.

Data requirements for cost-related analysis

The ability of TxDOT to perform a cost-benefit analysis is greatly limited as a result of the lack of linkage between installation data, a roadside inventory, and maintenance-related data. Maintenance expenditures can be calculated from maintenance-related documentation included

in an ISPE case study file but the installation date and costs of the particular device that received repair maintenance are normally not readily available. Routine maintenance-related information is also not readily available by date and location. The following information is required to perform a cost-related analysis as part of the ISPE process:

- Installation – The date of installation, related costs, and exposure of the installation crew. This cost item should include all the related expenditures such as traffic control, mobilization, and any related engineering fees.
- Routine Maintenance – The need for routine maintenance (frequency) and the related cost as well as the number of hours the crew is exposed to traffic.
- Repair Maintenance – Information regarding the ability to re-use the device after impact, the range of the extent of damage after impacts, the hours of crew exposure, and the need for special equipment or replacement elements.
- Geometric Characteristics – For the devices that are compared, the geometric characteristics should be known (e.g. straight median sections, exit gore areas; whether it is a rural or urban facility).
- Site-specific conditions - such as traffic volumes, etc.

CONCLUSIONS

The analysis of ISPE related data and in-service performance related calculations should be preformed with great care, ensuring that adequate sample sizes are obtained to enable statistically valid conclusions regarding, for example, the failure rate of a particular device. For cost-related calculations, such as cost-benefit analysis, installation and routine and repair maintenance costs should be available along with crash data (of sufficient sample size) and dates of installation and maintenance activities. Due to the nature of ISPE-related data, i.e. relationships with geometric site characteristics, impact conditions etc., the researcher/consultant should be careful to avoid bias in the calculations due to these and other factors.

CHAPTER 6: RECOMMENDATIONS FOR IN-SERVICE PERFORMANCE EVALUATION (ISPE) OF ROADSIDE SAFETY FEATURES

A two-phase ISPE process was developed and pilot tested to meet the specific needs of TxDOT. In Phase I, the data collection form includes basic information such as accident date, location, whether or not the vehicle overturned, whether or not the crash resulted in a fatality, identification of the specific roadside safety device involved in the crash, and an evaluation of whether the system performed as intended. If the Phase I process identifies a roadside safety device having a high rate of failure, a Phase II investigation of that device is recommended. A Phase II requires collection of more detailed information for each crash including the layout and specific features of the particular device that was impacted and a more detailed investigation into the impact performance of the device. ISPE site inspection forms and training materials along with a recommended ISPE procedure were prepared as part of the project.

Implementation of this two-phase approach enables more efficient use of limited resources. Phase I was developed to serve as an initial screening of the in-service performance of selected roadside safety devices. It is designed to be integrated into existing TxDOT maintenance practices with minimal demand on personnel and resources. The results of Phase I are used to quantify basic failure rates for each device investigated. The nature and cause of the failures are not directly quantified. However, the overall failure rate of a device can be used as an indicator for whether or not a problem exists. The failure rate for a given device can be compared with those for other devices in the same category of roadside safety hardware (e.g., guardrail end treatments or crash cushions), or the aggregate failure rate for different categories of roadside safety hardware can be compared against one another.

The more detailed Phase II analysis focuses additional resources only on the specific devices found to have an unreasonably high failure rate during the Phase I investigation. Phase II is designed to evaluate the causes of failures related to the performance of a device. In order to make such determinations, the data collection requirements are necessarily more detailed and labor intensive. Once the failure causes are known, recommendations can be formulated to improve impact performance through modification of the design and/or installation and maintenance practices.

A recommended plan for implementing the two-phase in-service performance evaluation process is described below.

PHASE I ISPE

Identify Roadside Safety Devices

It is recommended that the following categories of roadside safety devices be included in the Phase I ISPE: sign supports, guardrail, guardrail-to-bridge rail transitions, guardrail end treatments, and impact attenuation devices (i.e., crash cushions). Although bridge railings can be included if so desired, they were excluded by the project advisory committee due to the large variation of bridge railings in use on the highway system in the state of Texas, the limited extent of damage normally sustained to bridge railings during impact, and the small likelihood of such crashes being reported to TxDOT maintenance offices.

It is important to be able to identify the different device types within each of these categories so that their performance can be compared. The researchers prepared a list of all the approved devices in use within Texas for each of the five selected roadside safety feature groups recommended for inclusion in the ISPE process. A series of questions and descriptions of key features were developed to assist data collectors with the identification of each device.

It is expected that roadside safety features will continue to change and evolve in response to new crash testing requirements, changes in the vehicle fleet, maintenance considerations, etc. The data collection forms will need to be periodically revised as new devices are approved for use in Texas and others are removed from standards. One of the important roles of an ISPE program is to assist in the monitoring and evaluation of the in-field performance of new roadside safety hardware. A timely evaluation of new products could identify potential problems prior to widespread implementation of the device on Texas highways. The format and information prepared for the devices currently recommended for inclusion in the ISPE process will provide a framework for development of similar information for new devices.

Select Participating Offices

It is recommended that Phase I of the ISPE primarily involve maintenance offices from among the major metropolitan districts (e.g., Dallas, Houston, Fort Worth, San Antonio, Austin). Utilization of these districts, which account for the majority of single-vehicle run-off-road

crashes occurring in Texas, will limit the time required to collect a statistically significant sample of crashes for the various roadside safety devices of interest.

The maintenance offices should be selected from among these districts to provide a mixture of both urban and suburban/rural highway systems on which data can be collected. The different operating conditions (e.g., speed, ADT), roadway design characteristics (e.g., shoulder width and type, horizontal curvature), and roadside geometries (e.g., side slopes, ditch configuration) inherent between urban and rural roadways can influence impact conditions of run-off-road crashes and, hence, the failure rates of the roadside safety devices being investigated. Some devices such as impact attenuators are used primarily on urban freeways and, therefore, their evaluation will be comprised of crashes collected by urban maintenance offices.

To the extent practical, the participating maintenance offices should cover the spectrum of roadside safety devices included in the ISPE. For example, one district may predominantly use steel-post guardrail while another may prefer wood-post systems. Both systems should be included in an ISPE. Given that the maintenance offices will be selected from large, metropolitan districts that use a wide range of roadside safety devices, this should not be a major difficulty.

As with any program, if a genuine motivation or level of interest exists among the participants, the quality and completeness of the collected data would be expected to be high. The reverse is also true. Therefore, if volunteers can be found from among the maintenance offices, the ISPE process would have a better chance of success. For example, maintenance conferences can be used to introduce the benefits of an ISPE program, explain the general requirements for participants, and solicit volunteers. Volunteers need not be limited to the metropolitan districts.

Identify Personnel for Data Collection

Based on the system constraints faced by TxDOT and the ISPE framework developed under this project, the research team recommends that the data collection be performed by TxDOT maintenance personnel. For roadside safety devices other than sign supports, it is recommended that the inspector or maintenance foreman/supervisor perform the required site inspection after a crash and complete the Phase I ISPE form. This can be accomplished within the current responsibilities of these individuals without extra travel and with minimal extra time. A maintenance foreman/supervisor is generally dispatched to a crash site to assess safety at the

site and oversee roadway clearing and placement of any required delineation. An inspector is subsequently sent to the site to assess repair needs and costs. With appropriate training, either of these individuals would be able to complete the data collection form and other required documentation during a regularly scheduled visit to a reported crash site.

It is recommended that data collection for sign support crashes be accomplished by the team leader or senior member of a sign crew. Sign crews are responsible for the maintenance and repair of sign supports in a prescribed area. Different data collection forms were developed under this project for sign supports and all other roadside safety devices in recognition of differences in operations and personnel.

Define Data Collection Process

Data Collection Forms

Recommended site inspection forms for use in Phase I of the ISPE were developed and are included as [Appendix B](#). The Phase I site inspection forms were designed to ascertain two critical pieces of information: (1) the type of device that was impacted and (2) whether the device failed or functioned as intended. Using these two basic pieces of information, a first-level evaluation of the roadside safety devices of interest can be performed based on failure rate analysis.

All of the types of roadside safety devices currently approved for use in Texas are included in the forms. Basic questions and supplemental information guide the data collector in proper identification of the device. Training and supplemental information are drawn upon to assess whether or not the device failed or performed as intended. Photos and descriptions of common failure modes aid in this determination.

The data collection forms developed under this project were evaluated in a pilot project. Feedback obtained from participants in the pilot project was used to revise the forms. Two separate data collection forms are provided: one for signing and another for all other device groups. Two forms were deemed necessary to accommodate the different operational procedures and personnel used to maintain and repair sign supports and other roadside safety features.

Periodically, the data collection forms should be reviewed and modified as needed to incorporate new roadside safety devices approved for use in Texas or to remove obsolete devices that have been deleted from TxDOT standards. The format and questions prepared for the

devices currently included on the forms will provide a framework for development of similar information for new devices.

The benefits of monitoring and evaluating the in-field performance of new roadside safety hardware are obvious. A timely evaluation of new products can identify potential problems prior to their widespread implementation on Texas highways. Collection of data on devices that have been removed from standards may be beneficial for some period of time if the device has previously seen widespread implementation throughout the state. Information obtained on older devices may aid administrators in making decisions regarding how to approach the upgrading or replacement of these systems. If they are functioning well in the field, upgrading and replacement can be given a lower priority and critical resources can be used elsewhere. If the device is performing poorly, more attention and resources can be devoted to upgrading the devices in the field.

Data Collection Period and Sample Size

The data collection period required for the Phase I ISPE is a function of several factors including: the number of maintenance offices participating in the study, the frequency of roadside crashes occurring within the jurisdiction of these offices, the number of different roadside safety devices included in the study, and the number of crashes required to obtain a statistically significant sample for evaluation of impact performance (i.e., sample size). The sample size should be large enough to properly detect if potential problems exist with the devices being studied. Traditionally, the sample size is determined by various components including the power of the study (i.e., the probability of detecting a statistically significant association of a particular magnitude), the characteristics of the population (e.g., standard deviation), and the level of accuracy (e.g., 95 percentile) sought by the investigator.

The minimum required sample for the Phase I ISPE is a function of the failure rate threshold used in the analyses to determine if a given device (e.g., QuadGuard®, Energy Absorption Systems, Inc.) or group of devices (e.g., impact attenuators) are performing as intended. The minimum number of crashes required to analyze a given device or group of devices is presented below as a function of the selected failure rate threshold used to indicate whether a device is performing acceptably or unacceptably in the field.

- failure rate of 20 percent: a minimum of 165 crashes (or impacts) required for the analysis
- failure rate of 10 percent: 410 crashes (or impacts) minimum
- failure rate of 5 percent: 1150 crashes (or impacts) minimum
- failure rate of 2 percent: 9300 crashes (or impacts) minimum

The same number of crashes can be applied to each device. The smaller the selected failure rate threshold, the larger the required number of crashes. The numbers given above were estimated for a study power of 80 percent and a significance level (α) of 5 percent. Alternative sample sizes can be computed given the characteristics described above with the following equation:

$$n = \frac{15.698 \times \bar{p} \times (1 - \bar{p})}{d^2}$$

where,

$$d = \bar{p} - 1\%$$

$$\bar{p} = (\text{failure rate in percent} + 1 \text{ percent})/2$$

The Texas Department of Public Safety (DPS) crash database can be used to develop descriptive statistics for run-off-road crashes by variables such as object struck (e.g., guardrail), geographic location (e.g., county), frequency, and severity. This information can be used to develop an estimate for the time period required to collect a specified number of crashes given a group of locations (e.g., maintenance offices, districts, etc.) selected to participate in the study. As an example, consider a Phase I ISPE in which data are to be collected in Fort Worth, Houston, and San Antonio. The time period estimated to collect the number of crashes required for a Phase I ISPE is summarized in [Table 6](#) as a function of the selected failure rate threshold.

Table 6. Estimated Time Required to Collect Phase I Crash Data.

Failure Rate Threshold	10%	5%	2%
Number of Crashes Needed	410	1,150	9,300
Type of Device	Number of Months Required ¹		
End Treatment	4	11	90
Guardrails	6	17	136
Impact Attenuators	28	78	635
Signs	9	25	204

¹ If data are collected in Fort Worth, Houston, and San Antonio

Of course, expansion of the number of data collection sites would enable the study period to be reduced. As mentioned previously, it is recommended that data be collected in maintenance offices in all the major metropolitan districts as well as other interested districts across the state. Diversification of data collection sites (i.e., maintenance offices) throughout the state will help eliminate any bias in the sample.

Several factors may influence the selection of a failure rate threshold. A certain number of device failures are expected to occur due to exceedance of design impact conditions for the system. In other words, device failures would occur if the impact severity (which is a function of vehicle mass, impact speed, and impact angle) exceeds the design and test requirements for a particular device. As an example, the design impact conditions for longitudinal barriers (e.g., guardrail, median barrier, etc.) recommended in *NCHRP Report 350* include an impact speed of 62 mph (100 km/h) and an impact angle of 25 degrees.

In order to assess the percentage of crashes that exceed the design impact conditions, it is necessary to relate the test conditions to the impact speed and angle distribution of actual crashes. Unfortunately, data on real-world impact conditions are very limited due to the fact that data collection often requires in-depth investigation and reconstruction of crashes. One of the few available sources on real-world impact conditions are the Pole and Narrow Bridge studies conducted by Mak et al (15). When impact speed and angle are jointly considered, the data indicate that only 1.65 percent of impacts exceed the combined impact condition of 62 mph (100 km/h) and 25 degrees. While the percentage of crashes exceeding design impact conditions can be used as an indication of an expected failure rate, it should be noted that these data are over 20 years old and were collected at a time when the national speed limit was 55 mph (88.5 km/h).

More recent data suggest that the percentage of crashes that exceed the design impact conditions recommended in *NCHRP Report 350* has grown to over 5 percent on high-speed roadways (16). The reconstructed crash data indicate that impact speeds have not increased proportionately to posted speeds, and vehicles are leaving the road at higher impact angles than suggested in the older data. This difference may be due in part to the widespread use of anti-lock brakes, which provide more effective braking and permit vehicles to respond to steering input during full braking.

However, these data are considered conservative in the sense that they pertain only to reported crashes with a tow-away reporting threshold. Although the percentage of unreported

crashes is not known, it is believed to be significant. There is also a widely held belief that these crashes will tend to have lower impact speeds and impact angles than reported crashes. Therefore, the inclusion of unreported crashes would tend to reduce the percentage of crashes that exceed design impact conditions as a function of total crashes. Additionally, it should be noted that exceedance of design impact conditions does not always mean the device being impacted will fail and, conversely, failures can sometimes occur at impact severities below that of the design impact conditions.

In consideration of these factors, it is recommended that a failure rate of 2 percent be used as a threshold to establish if a given device is performing acceptably in the field. This rate can be adjusted if subsequent data or administrative policies so dictate. The data collection period associated with a 2 percent failure rate may be impractical for some device types or device groups such as impact attenuators. However, the resources required to conduct a Phase I analysis have been minimized to make longer-term studies feasible. Therefore, these crash levels should be obtainable for most of the roadside safety devices of interest. Of course the time required to complete the data collection will be a function of how many maintenance offices are collecting data.

Train Personnel

Adequate training is critical to the overall success of the ISPE process. Proper training or lack thereof can have a direct consequence on the quality and usefulness of the collected data. It is recommended that a member of the research team be involved with the training program at some level. This may be to train instructors (TxDOT employees or outside contractors) that will subsequently administer the training to personnel in the participating maintenance offices, or to directly train the maintenance personnel.

Prior to conducting the Phase I ISPE, training workshops should be conducted for the participating maintenance sections. Such training will not only serve the ISPE process, but should also have added value to the participating maintenance sections as it will increase awareness of the design, installation, and function of the devices included in the ISPE process.

The training program should include: an overview of the ISPE process, a review of the roadside safety devices for which data will be collected, a detailed discussion of the data collection forms and data collection process, and a practical session that includes in-field

training. The ISPE overview should contain elements such as the definition of an in-service performance evaluation, why is it important, and how the data will be used. The review of roadside safety devices should include a physical description of the device, a discussion of its purpose, and an explanation of how it functions. Critical elements and components of each device that can influence impact performance should be identified and described. Examples and discussion of failure modes for each device should be presented. This information is critical to the in-field determination of whether an impacted device performed acceptably or unacceptably.

It is recommended that the classroom portion of the training workshop be augmented with one or more site visits during which every participant will collect the desired information and take photographs of the scene. The collected data can then be reviewed, discussed, and used as a means of addressing questions and issues regarding the data collection process.

The research team developed training materials for use in the ISPE process. These training materials were used to conduct training of personnel in the maintenance sections participating in the pilot project conducted as part of this project. The reader is referred to [Chapter 4](#) and [Appendix E to H](#) for further details regarding the recommended training process. The training was well received and was instrumental in assisting maintenance personnel in the collection of quality data. The training materials are included on CD in [Appendix I](#) for use by TxDOT personnel or outside contractors as the basis for conducting training workshops in support of the Phase I ISPE process.

Collect Data

The primary data collection should be performed by TxDOT maintenance personnel that already visit the crash site as part of their routine responsibilities to assess damage to the roadside safety device impacted, determine repair requirements and costs, or (in the case of sign supports) perform needed repairs. As mentioned previously, it is recommended that an inspector or maintenance foreman/supervisor perform the required site inspection for roadside safety devices other than sign supports when dispatched to the crash site to perform other duties. It is recommended that data collection for sign support crashes be accomplished by the team leader or senior member of the sign crew dispatched to make needed repairs. It is essential to the success of the ISPE process that all individuals directly involved with the collection of data be included in the recommended training program.

The site inspections should be conducted prior to any impact-related repairs and/or maintenance work on the device. The research team recommends that the Phase I specific data collection form be completed by the designated person while at the site simultaneously with other inspections carried out as part of standard TxDOT procedure.

For each impact coded as a device failure on the data collection form, digital photographs should be taken at the scene to supplement the written documentation. The proper distinction between acceptable and unacceptable performance is critical to the proper evaluation of the in-service performance of the studied devices. The number of failed devices is not expected to be large: therefore, the effort required to document the failures should not be significant. Yet the photographs will be very valuable in regard to quality control and future review of the failure cases as background data for a Phase II study should one be warranted. They also provide material for inclusion in the ISPE report to illustrate impacts performance problems associated with a particular device.

Many maintenance offices already own digital cameras for use in other inspections that can be used in ISPE inspections. Digital format is preferred to facilitate the storage of the photos on electronic media for later use. Generally speaking, the photographs should document damage to the roadside safety device in the region of failure, vehicle tire paths (if visible), and vehicle damage (if vehicle is still present at time of inspection). More detailed recommendations regarding the number, subject, and location of photographs taken in support of the ISPE process are provided in [Chapter 4](#) and [Appendix G](#).

After performing the site inspection, completing the data collection form, and taking photographs of the scene (if the device was judged to have failed), a case file should be prepared so that pertinent information for the case can be organized and tracked. It is recommended that the case file include the following information:

- completed site inspection form (this includes the date of inspection, the date of the impact if available, location description, type of device impacted, and assessment of whether the device performed acceptably or unacceptably);
- digital media with the digital photographs taken during the site inspection (if the device was found to have performed unacceptably);

- grayscale printouts of the digital photographs taken during the site inspection (if the device was found to have performed unacceptably) – the printouts make review and assessment of the case easier and provide a backup in case the digital media fails at a later date; and
- copy of the associated accident report form if available for crashes in which the device was determined to have performed unacceptably.

As is apparent from this description, in most instances the case file will only contain the completed site inspection form. This minimizes the resources required to perform a Phase I ISPE. For the cases that involve a device failure, additional information is requested in the form of photographs and accident report form to help document the crash and the nature of the failure.

Analyze Data

It is recommended that information from the completed data collection forms be coded into a spreadsheet or simple database structure by personnel in the participating maintenance offices as part of their daily or weekly data logging and reporting work. A database structure developed by the research team for coding and analyzing the ISPE data obtained during the pilot study can be used for this purpose. The data should then be transferred to the Maintenance Division through the district office for compilation and analysis.

Alternatively, a knowledgeable contractor can be hired to assist TxDOT with the planning and conduct of the Phase I ISPE. Responsibilities of the contractor would include:

- review and update data collection forms as needed to include new devices approved for use in Texas or delete obsolete devices from the study,
- conduct training workshops for participating maintenance sections,
- meet periodically with offices collecting data to address problems and issues that arise during the data collection process,
- collect completed data collection forms from the participating maintenance offices and code information into a database,
- perform quality control on the collected data to help ensure completeness and accuracy,
- review failure cases (photographs),

- analyze data and compute failure rates for devices and/or device groups included in the Phase I ISPE, and
- prepare report and provide results to TxDOT Maintenance Division.

Failure rates can be readily computed after coding of the ISPE data. The failure rate is simply calculated as follows:

$$f = (N_f / N_T) \times 100$$

where,

- f = failure rate in %
- N_f = number of crashes resulting in failure
- N_T = total number of crashes

The failure rate can be computed for a group of devices or specific type of device if enough observations exist. In the event the failure rate is above the pre-determined threshold (5 percent, 10 percent, etc.), further analysis should be performed with the data collected.

As an example, consider a failure rate threshold of 5 percent for which a total of 1150 crashes were documented for a specific type of device. If the number of crashes resulting in failure of the device was 75, the failure rate for the device would be $(75/1150) \times 100 = 6.5$ percent. Given that the failure rate exceeds the selected failure threshold of 5 percent, the device considered in this example should be given consideration for further investigation.

The results of the Phase I analyses should be incorporated into a report. The data (e.g., types of devices, number of crashes, failure rates, etc.) can be cross-tabulated in single and 2x2 tables. The analyses results can also be separated by location (e.g., district) to help assess if any potential performance problems are localized (which might be indicative of installation or maintenance issues) or statewide (which might indicate a system deficiency). [Table 7](#) and [Table 8](#) present a simple example of tabulated results for impact attenuators.

Finally, the Phase I report should provide recommendations for Phase II ISPE for those devices that exceed the predetermined failure threshold. If more than one device type exceeds the selected failure threshold, the failure rates of these devices can serve as a means of prioritizing any needed Phase II evaluations.

Table 7. Number of Failures for Impact Attenuator Group.

Device Worked as Intended?	Number of Crashes
Yes	20
No	8
Total Crashes	28

Table 8. Number of Failures by Type of Impact Attenuators.

Type of Device	Number of failures
QuadGuard® (Energy Absorption Systems, Inc)	0
GREAT® (Energy Absorption Systems, Inc)	1
TRACC (Trinity Industries)	0
React 350® (Energy Absorption Systems, Inc)	0
Hexfoam® (Energy Absorption Systems, Inc)	6
Hydrocell® (Energy Absorption Systems, Inc)	1
TX Barrels® (TxDOT non-proprietary)	0
Total Failed Crashes	8

PHASE II ISPE

In Phase I only failure rate is known, not the probable cause of failure. Phase II is designed to more thoroughly investigate devices found to have an unreasonably high failure rate during the Phase I investigation. The intent is to perform a specialized study to develop a more in-depth understanding of the underlying causes of the device failures and determine if some corrective action is needed to improve its safety performance. In order to make such determinations, the data collection and analysis requirements are necessarily more detailed and labor intensive. Once the failure causes are known, recommendations can be formulated to improve impact performance through modification of the design and/or installation and maintenance practices. The recommended procedures for conducting Phase II are provided below.

Identify Roadside Safety Devices

The roadside safety devices included in a Phase II ISPE will be those found in a Phase I study to have a failure rate above the pre-determined threshold. The Phase II ISPE may focus on a category of devices or one or more specific devices within a category depending on how the Phase I data was analyzed. The categories of roadside safety devices that have been considered for a Phase II ISPE are the same as those included in the Phase I ISPE, namely: sign supports, guardrail, guardrail-to-bridge rail transitions, guardrail end treatments, and impact attenuation devices (i.e., crash cushions).

For a Phase II investigation, the positive identification of a specific device type is critical. The researchers prepared a list of all the approved devices in use within Texas for each of the five selected roadside safety feature groups recommended for inclusion in the ISPE process. A series of questions and descriptions of key features were developed to assist data collectors with the identification of each device.

It is expected that roadside safety features will continue to change and evolve in response to new crash testing requirements, changes in the vehicle fleet, maintenance considerations, etc. The data collection forms will need to be periodically revised as new devices are approved for use in Texas and others are removed from standards. The format and information prepared for the devices currently recommended for inclusion in the ISPE process will provide a framework for development of similar information for new devices.

Select Participating Offices

The researchers recommend involving the same offices as in Phase I of the ISPE. This consistency will make use of the experience and training these offices received during the Phase I investigation. It will also provide the same mixture of geographic location, land use (urban versus rural) and other characteristics associated with Phase I that raised questions about the device being investigated. However, the maintenance offices participating in Phase II may need to be modified based on the device being evaluated. For example, some districts may not use a particular type of device and need not be included. If this is the case, maintenance offices in other districts that use the device can be selected for participation.

Identify Personnel for Data Collection

It is recommended that the Phase II data be collected by the same TxDOT maintenance personnel used in the Phase I investigation that prompted continuation to Phase II. For roadside safety devices other than sign supports, it is recommended that the inspector or maintenance foreman/supervisor perform the required site inspection after a crash and complete the Phase II ISPE form for the specific device being investigated. As in Phase I, this site inspection is expected to be accomplished during a site visit that corresponds with the inspector/foreman's existing responsibilities. If the device being investigated in Phase II is a sign support system, it is recommended that data collection be performed by the team leader or senior member of the sign crew dispatched to the crash site to make repairs.

Define Data Collection Process

Data Collection Forms

Recommended site inspection forms for Phase II of the ISPE were developed under this project and are included in this report as [Appendix C](#). The Phase II site inspection forms were designed to collect sufficient information to help identify the cause of a device failure in a crash. Questions are used to guide the data collector in evaluating critical components of the system that could play a role in failure of the device.

While all of the types of roadside safety devices currently approved for use in Texas are included in the Phase II forms, the Phase II process is intended to be specific to a particular group or type of devices. Therefore, prior to the Phase II study, the existing data collection forms should be reviewed and modified as needed to eliminate unneeded data items (i.e., those that pertain to roadside safety devices other than the type being studied) and to add any device specific items that may have been overlooked

Two separate data collection forms are provided for Phase II: one for signing and another for all other device groups. Two forms were deemed necessary to accommodate the different operational procedures and personnel used to maintain and repair sign supports versus other roadside safety features. Completion of the more detailed Phase II inspection form will require more time than the Phase I form. However, since Phase II is device specific, there will be fewer crashes that will need to be documented compared to the more general Phase I investigation.

Data Collection Period and Sample Size

The data collection period required for Phase II is a function of several factors including: the number of maintenance offices participating, the number of different roadside safety devices included, the frequency of roadside crashes occurring within the jurisdiction of the participating offices, and the number of failed crashes required to obtain sufficient information to determine failure causation factors. Each failed device investigated will add significantly to the understanding of the device's impact performance.

Train Personnel

Prior to conducting the Phase II ISPE, training workshops should be conducted for the participating maintenance sections. The training program should include: an overview of the ISPE process, a detailed review of the roadside safety device that is the focus of the Phase II evaluation and for which data will be collected, a detailed discussion of the data collection forms and data collection process, and a practical session that includes in-field training. Proper training is essential to help ensure the quality and completeness of the collected data.

The review of the roadside safety device being investigated should include a physical description of the device, a discussion of its purpose, an explanation of how it functions (including the role of critical elements and components of the device and how that can influence impact performance), and explanation of proper installation and maintenance procedures. Examples and discussion of failure modes for each device should be presented.

Even if the same personnel that collected the Phase I ISPE data participate Phase II, they should attend the more specific Phase II training course to gain in-depth understanding of the device being studied and the data collection forms being used.

As in Phase I, it is recommended that the classroom portion of the training workshop be augmented with one or more site visits during which every participant will collect the desired information and take photographs of the scene. The collected data can then be reviewed, discussed, and used as a means of addressing questions and issues regarding the data collection process.

The research team has developed training materials for use in the ISPE process. These training materials were used to conduct training of personnel in the maintenance sections participating in the Phase II pilot study conducted as part of this project. The reader is referred to

[Chapter 4](#) and [Appendix G](#) for further details regarding the recommended training process. The training materials are included on a CD in Appendix I for use by TxDOT personnel or outside contractors as the basis for conducting training workshops in support of the Phase II ISPE process.

Collect Data

The primary data collection should be performed by TxDOT maintenance personnel that already visit the crash site as part of their routine responsibilities. As mentioned previously, it is recommended that an inspector or maintenance foreman/supervisor perform the required site inspection for roadside safety devices other than sign supports when dispatched to the crash site to perform other duties. It is recommended that data collection for sign support crashes be accomplished by the team leader or senior member of the sign crew dispatched to make needed repairs.

The site inspections should be conducted prior to any impact-related repairs and/or maintenance work on the device. The research team recommends that the Phase II data collection form be completed by the designated person while at the site simultaneously with other inspections carried out as part of standard TxDOT procedure.

Photographs form an essential part of the Phase II site inspection. Digital photographs should be used to document damage to the roadside safety device in the region of failure, vehicle tire paths (if visible), and vehicle damage (if vehicle is still present at time of inspection). Photographs should document the condition of all key components of the system that may have played a role in failure of the device. More detailed recommendations regarding the number, subject, and location of photographs taken in support of the Phase II ISPE process are provided in [Chapter 4](#) and [Appendix G](#).

After performing the site inspection, completing the data collection form, and taking photographs of the scene (if the device was judged to have failed), a case file should be prepared so that pertinent information for the case can be organized, tracked, and analyzed. It is recommended that the case file include the following information:

- completed site inspection form;
- digital media with the digital photographs taken during the site inspection;
- grayscale printouts of the digital photographs taken during the site inspection;

- maintenance records associated with the repair of the device; and
- a copy of the associated accident report form.

Analyze Data

It is recommended that a knowledgeable contractor be hired to assist TxDOT with the planning, conduct, and analysis of the detailed Phase II ISPE. Responsibilities of the contractor would include:

- review and update data collection forms as needed to be device specific,
- conduct training workshops for participating maintenance sections,
- meet periodically with offices collecting data to address problems and issues that arise during the data collection process,
- conduct visits to sites of crashes in which the device failed,
- collect completed data collection forms from the participating maintenance offices and code information into a database,
- perform quality control on the collected data to help ensure completeness and accuracy,
- conduct in-depth review of all failure cases,
- analyze data and determine causes of device failures, and
- prepare report and provide results to TxDOT Maintenance Division.

The results of the Phase II analyses should be incorporated into a report. The report should document the specific failure modes identified and whether these failure modes are related to maintenance, design, or installation problems. Finally, the report should provide recommendations for addressing any identified deficiencies of the device and improving its impact performance.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

THE ISPE PROCESS RECOMMENDED TO TXDOT

The recommended TxDOT-ISPE process is described in [Chapter 6](#). It was developed using an analysis as discussed in [Chapter 3](#) and a pilot test described in [Chapter 4](#). [Chapter 5](#) discusses the data analysis procedures and recommendations for the TxDOT-ISPE process.

THE ISPE DILEMMA

The objectives for an ISPE as listed in the background of this paper are commendable. Unfortunately there exists a disparity between the needs of the researcher to identify particular problems related to the use of a particular device and the available resources for a TxDOT-ISPE process (such as time and manpower).

The primary purpose for any roadside safety device is to protect motorists from more severe crashes. By the time that FHWA approves it for use, a device has successfully passed a series of crash tests under severe impact conditions. Therefore, when a roadside safety feature is installed in the field, there is an underlying assumption that the device will perform as intended. However, the ultimate measure of the success of a device lies in its in-service performance and ability to save lives and reduce injury. There are a number of reasons why a device may perform differently in the field than on the test track. The reasons may include:

- Installation-related issues, e.g. failure to install the device according to specifications, deviation from the original materials, etc. For example, this can include sign post stub heights that are too high, installation of guardrail posts in concrete to reduce mowing costs, etc.
- Layout issues, e.g., roadside slope, grading, approach, flaring, or offset of the system. This refers to any deviation from the original layout used in the crash tests of the device.
- Maintenance issues related to the system, such as damage or degradation of the system that can influence its performance.

- Replacement-related issues (see installation related issues).
- Inappropriate application of the device for the particular site and conditions. This can include roadside characteristics such as slopes, offset of the system relative to the edge of the traveled lane, clearance provided behind the system, etc.
- Changes in the traffic or operational environment, e.g., the vehicle fleet are constantly changing and particular vehicles or impact conditions may be outside the design parameters of the system.

DEVELOPMENT OF AN ISPE PROCESS FOR TXDOT

The research team found that the development of an ISPE is complicated and requires careful consideration of a range of issues within the constraints of a limited budget and human resources. The success of an ISPE depends not only on the development of a practical process but also on the cooperation of personnel within the state DOT.

BENEFITS OF AN ONGOING ISPE PROCESS AT A STATE DOT

An ongoing ISPE process at Phase II level will have substantial benefit for a State DOT but, even if the ongoing ISPE process consists of an initial screening phase with periodic Phase II studies as required, it will still render significant benefits to the state DOT by improving the decision-making process regarding approval, application, and maintenance of roadside safety features.

TxDOT also continuously implement new designs and over time various changes occur that can impact the impact performance of roadside safety devices and therefore their ability to reduce injuries:

- Changes in maintenance priorities. Limited budgets may reduce the ability for certain areas to replace, for example, guardrail posts or may affect the ability of an area to upgrade existing furniture to current state of the practice (e.g. the implementation of blockouts).
- Changes in maintenance practices. Limited budgets have forced TxDOT to reconsider the composition of the workforce, and various changes are currently being implemented in an effort to optimize the benefits that can be

achieved from current low budget levels. These changes in practice can result in changes to current approaches to the maintenance of roadside safety features, and a continuous ISPE process will identify any adverse effects such a change.

- A continuous ISPE process will result in larger sample sizes and will, therefore, more accurately identify those devices that warrant the more detailed Phase II ISPE.
- Changes in the vehicle fleet. These changes can be related to vehicle design features, changes in the size and weight of vehicles, and proportions of different vehicle types utilizing highway facilities.

A continuous ISPE process also allows for timely feedback to researchers and developers of roadside safety features. The results of a continuous ISPE process can also have a significant impact on the crash test requirements for these devices as these tests should also take cognizance of changes in the vehicle fleet and impact conditions.

ADDITIONAL BENEFITS OF AN ISPE PROCESS

Besides the benefits reported by the participants in the project pilot test, the implementation of a TxDOT-ISPE process may allow for the timely and informed assessment of current crash test procedures and the updating thereof to ensure that the crash test procedure remain representative of real impact conditions. The results of the ISPE process can also provide information to FHWA to allow them to follow up on initial approvals that are currently based on a limited number of crash tests to ensure proper performance of a device.

REFERENCES

1. Ross, H.E. Jr., Sicking, D.L., Zimmer, R.A., and Michie, J.D. *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, Transportation Research Board, National Cooperative Highway Research Program Report 350, Washington, D.C., 1993.
2. Michie, J.D., and Bronstad, M.E. *Location, Selection, and Maintenance of Highway Traffic Barriers*, National Cooperative Highway Research Program Report 118, Transportation Research Board, Washington, D.C., 1971.
3. Michie, J.D. *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report 230, Transportation Research Board, Washington, D.C., 1981.
4. Van Zweden, J., and Bryden, J.E., *In-service Performance of Highway Barriers*, Report No. NYSDOT-ERD-77-RR51, New York State Department of Transportation, Albany, New York, July 1977.
5. Ray, M.H., Weir J., and Hopp, J., *National Cooperative Highway Research Program Report 22-13: In-Service Performance Evaluation of Traffic Barriers*, Final Report 22-13, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., February 2001.
6. Griffin, L.I. III, *An Analysis of Accidents on Turned Down Guardrail Ends in the State of Texas (Calendar Year 1989)*, Report 9901-H, Texas Transportation Institute, College Station, Texas, May 1991.
7. Ivey, D.L., Bronstad, M.E., and Griffin, L.I. III, *Guardrail End Treatments in the 1990s*, Transportation Research Record 1367, Transportation Research Board, National Research Council, Washington, D.C., undated circa 1992.
8. Easton, S., *In-service Evaluation of the ET-2000 Guardrail End Treatment*, Informal Presentation, Transportation Research Board, Washington, D.C., January 9, 1996.
9. FHWA Texas Division, *Guardrail Extruder Terminal, Process Review - Final Report*, FHWA Texas Division, April 1996.
10. Mak, K.K., and Sicking, D.L., *Continuous evaluation of in-service highway safety feature performance*, Final Report 482, Prepared for Arizona Department of Transportation in cooperation with U.S. Department of Transportation, Federal Highway Administration, September 2002.

11. McClanahan, D., Albin, R.B., and Milton, J.C., *Washington State Cable Median Barrier In-Service Study*, Transportation Research Board, National Research Council, Washington, D.C., 2004.
12. Worcester Polytechnic Institute, Impact Monitoring System - Worcester, MA, <http://www.wpi.edu/Academics/Depts/CEE/Impact/ISPE/IMS/ims.html> accessed on October 24th, 2001.
13. Miaou, S.-P., and Bullard, L. *Rollover Causation and Mitigation Study*. TTI Research Report 474100-00001. Texas Transportation Institute, College Station, Texas, 2001.
14. Corel Corp. Ltd. *Paradox for Windows V9*. Ottawa, Ontario, 2000.
15. Mak, K.K., Sicking, D.L., and Ross, H.E., Jr., *Real-World Impact Conditions for Ran-Off-the-Road Accidents*, Transportation Research Record 1065, Transportation Research Board, Washington, D. C., January 1986.
16. Bligh, R.P., Miaou, S., and Mak, K.K., *Recovery Area Distance Relationships For Highway Roadsides*, draft final report on NCHRP Project 17-11, Transportation Research Board, Washington, D. C., August 2004.

**APPENDIX A:
ANALYSIS OF IMPACTS WITH ROADSIDE SAFETY
FEATURES IN TEXAS (TASK 3 OF PROJECT 0-4366)**

A1. INTRODUCTION

Several generations of roadside features have been developed to improve safety, but the effectiveness of these features in the field has not been fully investigated. While crashworthiness criteria have been updated in NCHRP Report 350 to reflect the state of the art, the crash tests are based on idealized installations of features and limited impact conditions. In field installations, the roadside features may be located on a slope, subjected to the effects of settlement, possibly improperly installed, and maintained less often than prescribed. In addition, in real-world conditions, vehicles can strike the safety features at angles, speeds, and orientations very different than those prescribed in a controlled testing environment. Thus, the ultimate test of these safety features lies in their actual in-service performance in the field.

This report presents the results of the analysis performed to fulfill the requirements of Task 3. The aim of this analysis consists of investigating the characteristics of crashes involving roadside safety features in Texas. Dominique Lord from the research team carried out the exploratory analysis with crash statistics maintained by DPS. The analysis was aimed at answering these specific questions:

- How often do crashes involving different types of roadside features happen?
- Where do they occur?
- What types of crashes occur more often than others?
- What types of vehicles are involved in these crashes?

This report is divided into four chapters. [Chapter A1](#) describes the general characteristics of crashes involving the selected roadside safety features. [Chapter A2](#) covers detailed statistics on each of the different roadside features. [Chapter A3](#) contains a description about the severity of crashes and the types of vehicles involved with a roadside feature. [Chapter A4](#) summarizes the findings revealed during the exploratory analysis.

A2. THE DATA

This section describes the characteristics of the crash data used to carry out the analysis on the safety of roadside safety features. The research team used data for the period covering 1997 to 1999 inclusively. The accident database is separated into five distinct components that are linked by a common accident identification number:

- **ACCIDENT DATABASE:** This file describes the characteristics of the crash. This file has one entry per line and describes variables such as the location, time and severity of the collision.
- **VEHICLE/DRIVER DATABASE:** This file describes the characteristics of each vehicle and the driver involved in the crash. The file has one entry per vehicle and describes variables such as the type of vehicle, type of model, vehicle registration, and gender of the driver.
- **OCCUPANT DATABASE:** This file describes the characteristics of each occupant of a vehicle involved in the crash such as the age, gender, and severity of injuries for the occupant. The file has one entry per occupant.
- **ROAD DATABASE:** This file contains information on every roadway section under the jurisdiction of the Texas Department of Transportation (TxDOT). The record contains current characteristics of the roadway such as lane width, number of lanes, and type of pavement among others. This file has one entry per homogeneous roadway section, as defined by TxDOT.
- **MERGED DATABASE:** This file combines the ACCIDENT and ROAD databases into one common database. This file has one entry per crash.

For this project, the researchers only used the VEHICLE and MERGED databases, since the analysis was performed for state maintained highways. The researchers executed the data reduction process into three steps. The first step involved the transformation of the SAS files into DBF format (database). The DBF format allows more flexibility for conducting the exploratory analysis of data. The second step consisted of linking all files together for the period of 1997 to 1999 into one common database. The third step involved the actual exploratory analysis of the data with Paradox (14). The results of the exploratory analysis are presented in [Chapter A3](#).

A3. ANALYSIS OF THE CRASH DATA

This section describes the characteristics of crashes involving roadside safety features in the state of Texas. The tables and graphs represent crashes that occurred on the TxDOT maintained highway system between 1997 and 1999 inclusively. It should be emphasized that the statistics presented in this report are for reported crashes only. Many crashes are not reported to governmental authorities; the magnitude of the problem is unknown at this time. In fact, the likelihood for a crash not to be reported is dependent on the roadside device (e.g., traffic signs vs. guardrail) and the type of vehicle (passenger cars vs. large trucks) among others. Thus, the results of the exploratory analysis are bounded by this limitation.

This chapter is divided into three sections. [Section A3.1](#) contains information on the general characteristics of crashes occurring on TxDOT maintained highways. [Section A3.2](#) covers the characteristics of crashes for each roadside safety feature separately. [Section A3.3](#) includes a description on the severity and types of vehicles involved in a crash with a roadside feature.

A3.1 Characteristics of Crash Data Involving Roadside Safety Features

At the beginning of the project, the members of the TxDOT review committee and the researchers at TTI agreed to evaluate a restricted number of roadside safety features that were deemed to be the most relevant for this project. [Table A1](#) depicts the selected roadside safety features. These features are defined according to variables used on the accident form. The results of this task in the study enabled the research team to select the appropriate roadside safety features to include in the TxDOT-ISPE process.

Table A1. Selected Roadside Safety Features.

Features	Features	Features
Highway Sign (20*)	Mailbox (31)	Side of Bridge (41)
Guardrail (23)	Median Barrier (39)	Attenuation Device (45)
Luminary Pole (29)	End of Bridge (40)	Concrete Barrier (56)
* Object code number on the DPS accident form		

Between 1997 and 1999, a total of 925,805 crashes occurred in Texas. During this period, 513,495 happened on the TxDOT maintained highway system. This maintained system spans over 737,900 miles. From the crashes that occurred on the state maintained highways, 61,304 collisions involved one of the nine roadside safety features presented in [Table A1](#). These crashes account for less than 7 percent of all crashes occurring in the state. These statistics are summarized in [Table A2](#).

Table A2. Crashes by Severity (1997-1999).

Severity	Roadside Safety Features	TxDOT Maintained Highway	State of Texas
Fatal	909	7,090	9,345
Injury A	3,990	32,162	52,223
Injury B	11,807	94,759	169,614
Injury C	17,250	209,926	389,201
PDO	27,348	169,558	305,422
Total	61,304	513,495	925,805

[Figure A1](#) illustrates the number of crashes per year by severity for the selected roadside safety features. This figure reveals that the number of crashes is fairly consistent with about 20,000 crashes annually. The number of crashes slightly decreased between 1997 and 1999.

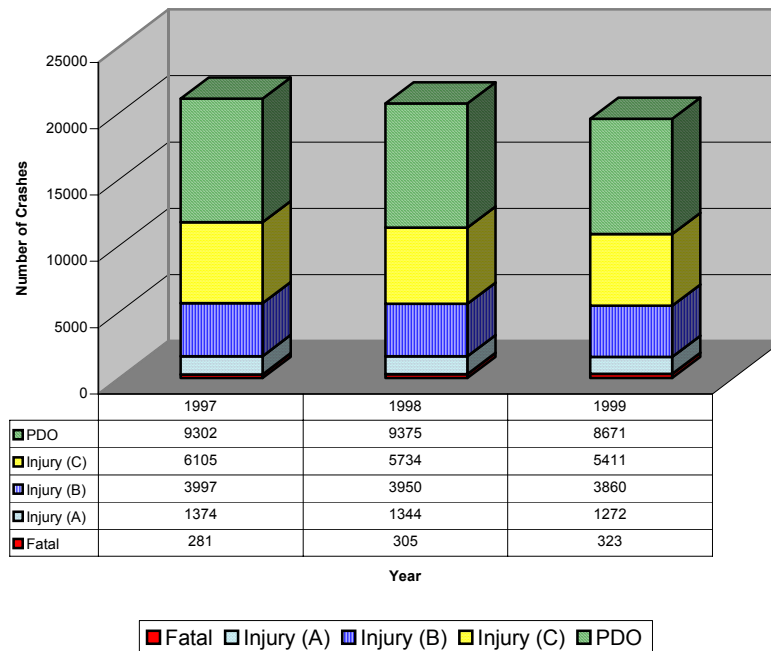


Figure A1. Crashes Involving Roadside Safety Features by Year (1997-1999).

Figures A2 and A3 show the number of crashes by county and by TxDOT administrative district. The figures reveal that more than two thirds of all crashes occur in the largest TxDOT districts: Houston, Dallas, Fort Worth, San Antonio, and Austin. It should be pointed out that many counties located in Western Texas have less than five crashes in a three-year period.

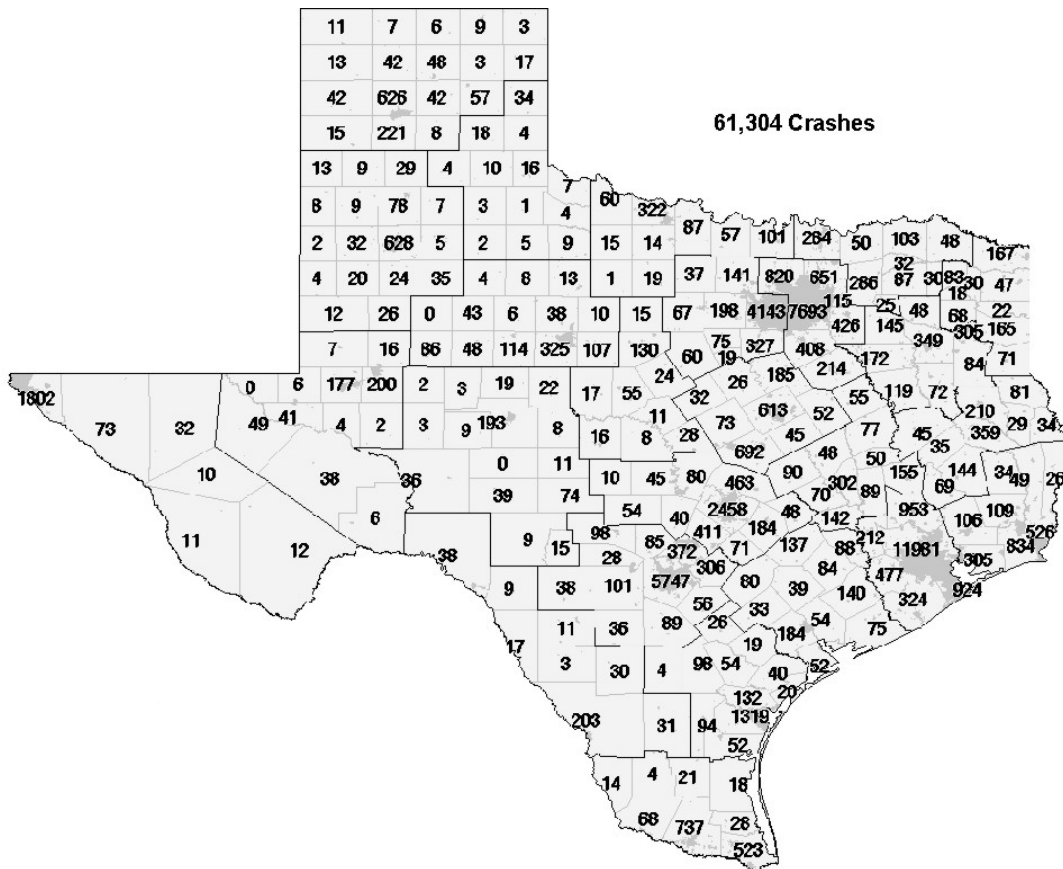


Figure A2. Number of Crashes by County (1997-1999).

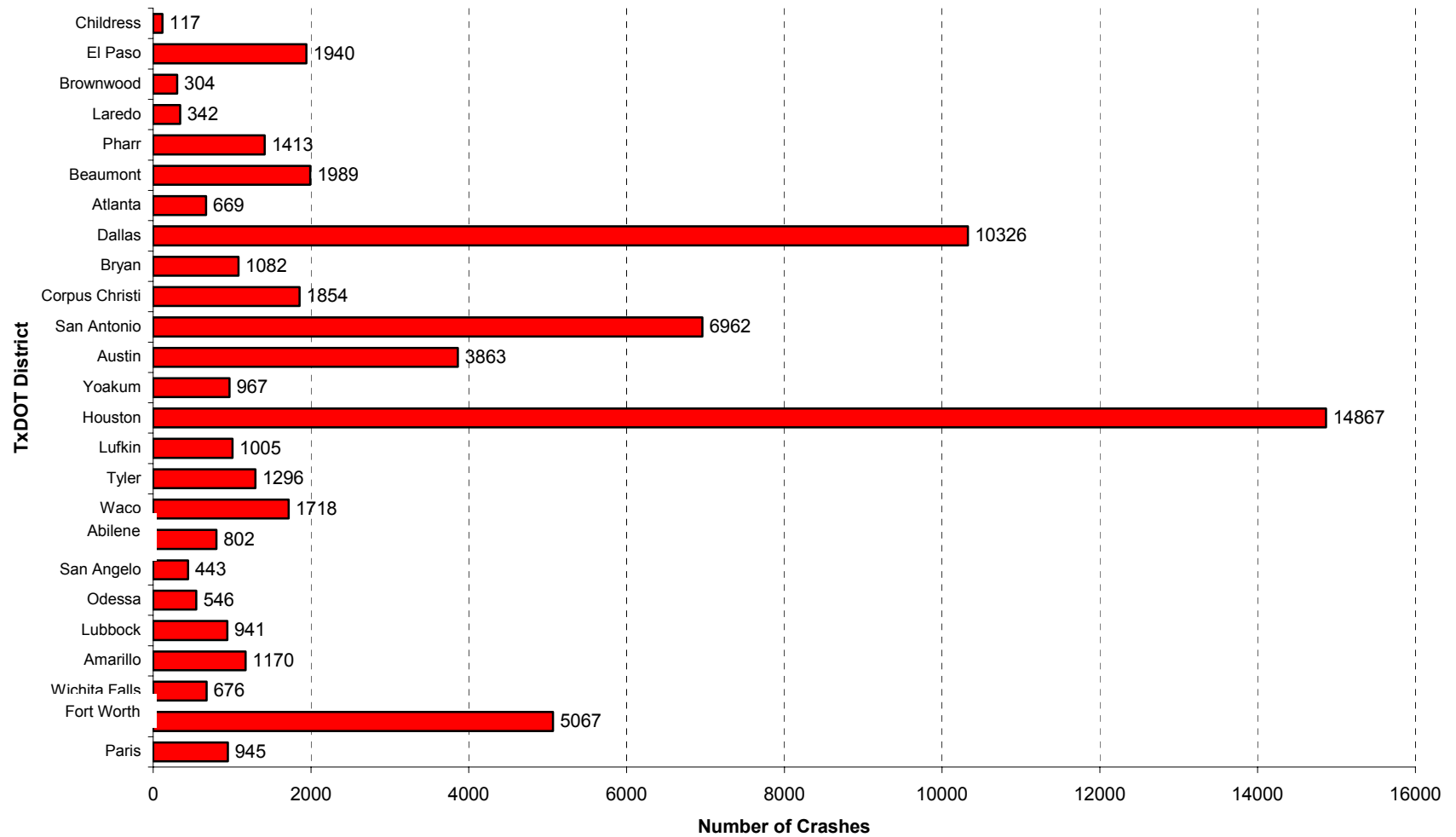


Figure A3. Number of Crashes by Regional TxDOT District (1997-1999).

Figure A4 illustrates the number of crashes by road type. This figure shows that more than 60 percent of all crashes occur on interstate and urban freeways. Nonetheless, a relatively high percentage of collisions (40 percent) takes place on state maintained arterial and collector roads.

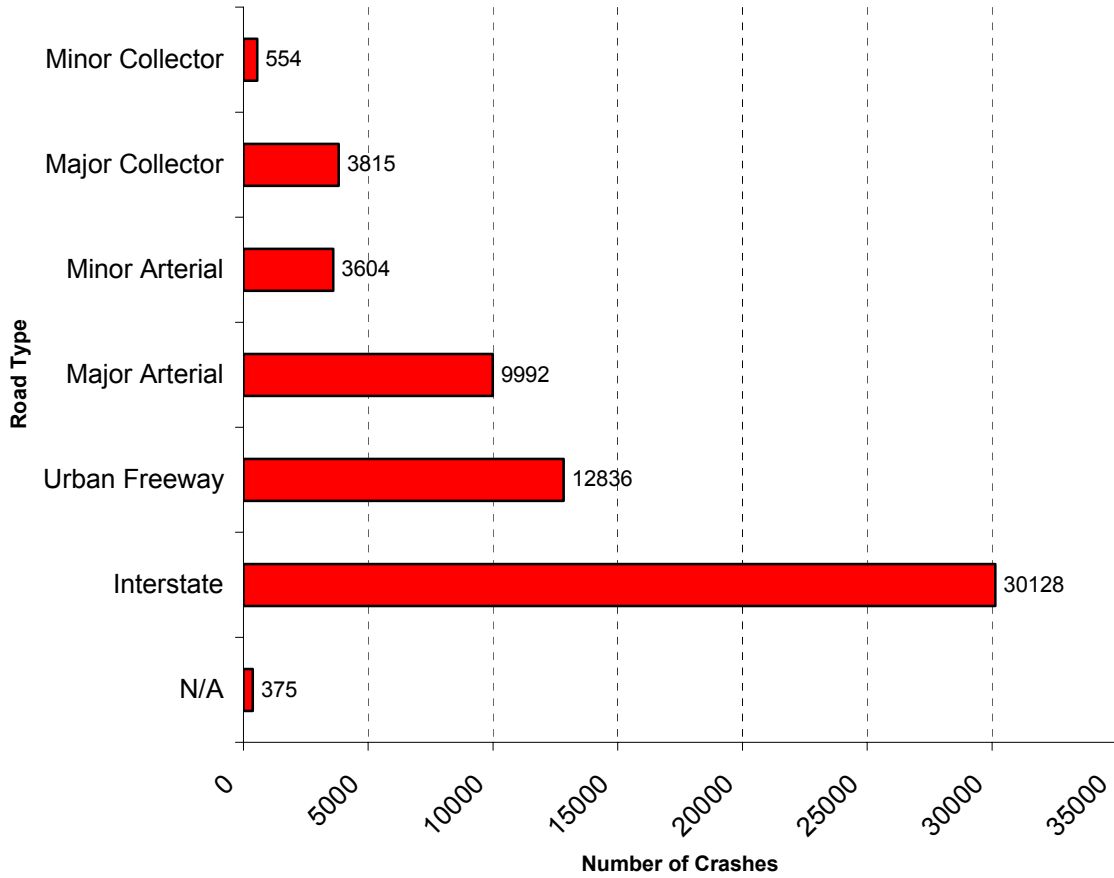


Figure A4. Number of Crashes by Road Type (1997-1999).

Figure A5 illustrates the number of crashes by alignment type. About 88 percent of all crashes involving a roadside safety feature occur on a straight alignment. Previous work on this topic has shown that crashes occur 70 percent of the time on straight alignment (Miaou and Bullard, 2001). It should be noted, however, that the study has been performed with a weighted sample. It is estimated that less than 0.5 percent of crashes happened on either a grade or on a hill.

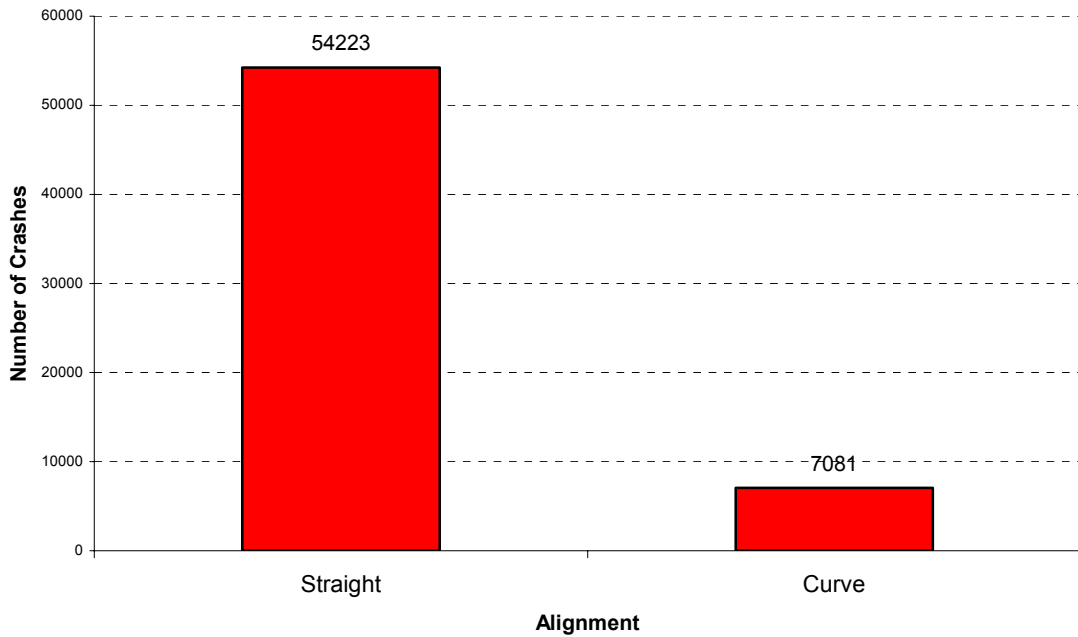


Figure A5. Number of Crashes by Alignment Type.

Table A2 and Figure A6 summarize the number of crashes by time of day and by lighting condition, respectively. Table A2 shows that the number of crashes involving a roadside safety object peaks during the afternoon peak period (2-6 pm). Figure A6 reveals that about half of the crashes occur during daylight conditions.

Table A3. Number of Crashes by Time of Day (1997-1999)

Time Period	Number of Crashes	Time Period	Number of Crashes	Time Period	Number of Crashes
0:00-0:59	2,592	8:00-8:59	2,641	16:00-16:59	3,133
1:00-1:59	2,592	9:00-9:59	2,289	17:00-17:59	2,957
2:00-2:59	3,437	10:00-10:59	2,280	18:00-18:59	2,665
3:00-3:59	2,272	11:00-11:59	2,538	19:00-19:59	2,418
4:00-4:59	1,660	12:00-12:59	2,602	20:00-20:59	2,244
5:00-5:59	1,833	13:00-13:59	2,631	21:00-21:59	2,275
6:00-6:59	2,473	14:00-14:59	3,013	22:00-22:59	2,472
7:00-7:59	2,737	15:00-15:59	3,050	23:00-23:59	2,500

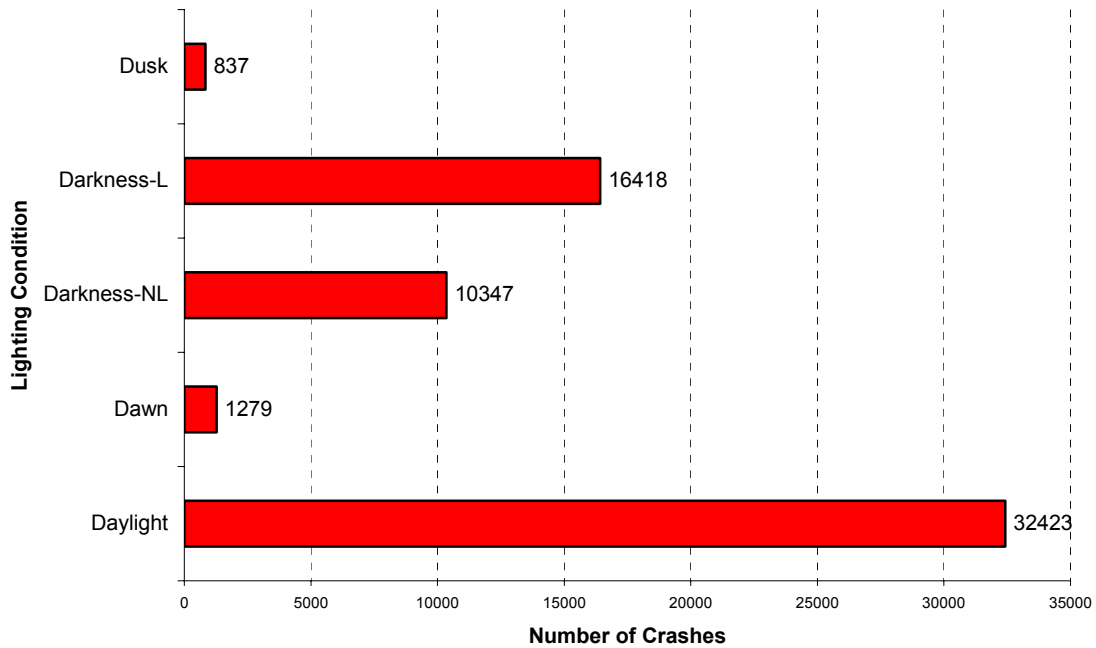


Figure A6. Number of Crashes by Lighting Condition (1997-1999).

Figure A7 illustrates the number of crashes by the day of the week. This figure demonstrates that crashes occur more frequently on weekends. There are about 33 percent more crashes on a Saturday or Sunday than on a typical weekday.

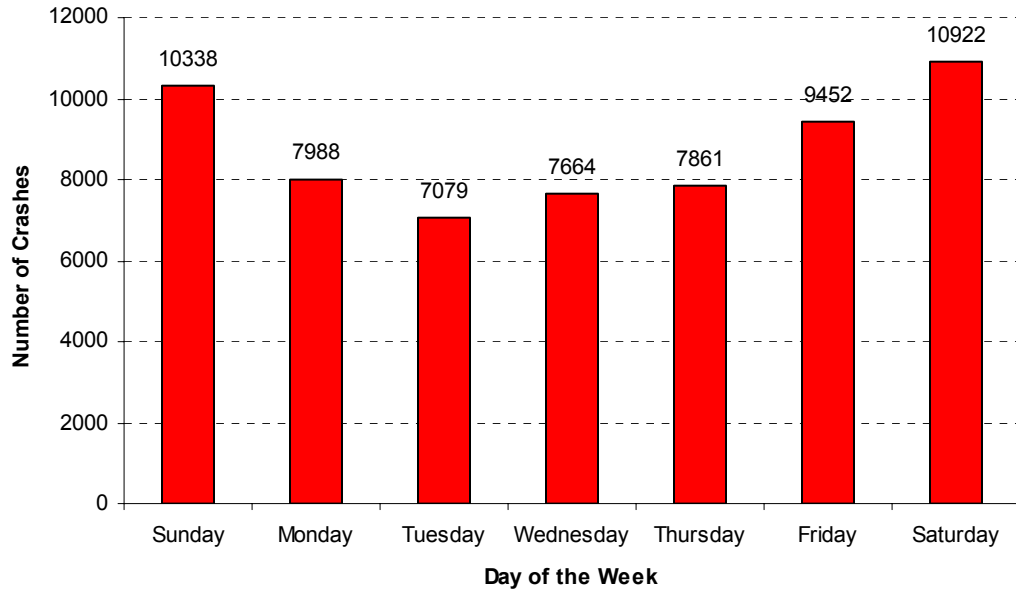


Figure A7. Number of Crashes by Day of the Week (1997-1999).

Figure A8 illustrates the number of vehicles involved in a crash. This figure reveals that about 73 percent of crashes are classified as a single-vehicle collision. It should be pointed out that in about 5 percent of single-vehicle crashes, another object was hit first before hitting one of the nine roadside safety features (the other objects were reported as the first harmful event for the crash rather than any one of the roadside safety features). Single-vehicle crashes are described in greater detail in Section A3.3.

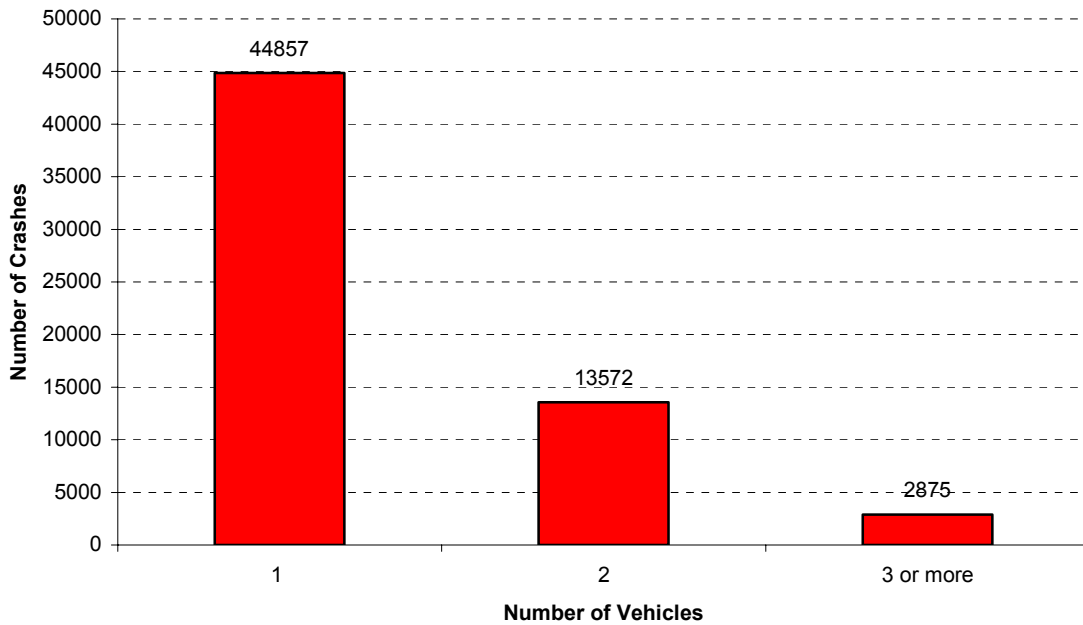


Figure A8. Number of Vehicles in the Crash (1997-1999).

Figure A9 exhibits the number of crashes per mile for different groups of traffic flow. The researchers noted that the traffic flow and the segment length used for the calculation presented in this figure were not validated by other means. They found some outliers and removed for this part of the analysis. Thus, this graph should be interpreted as a general presentation of the relationship between flow and the number of crashes.

Figure A9 shows that the number of crashes increases, peaks and then decreases as traffic flow increases. This relationship is known to follow a Gamma function.

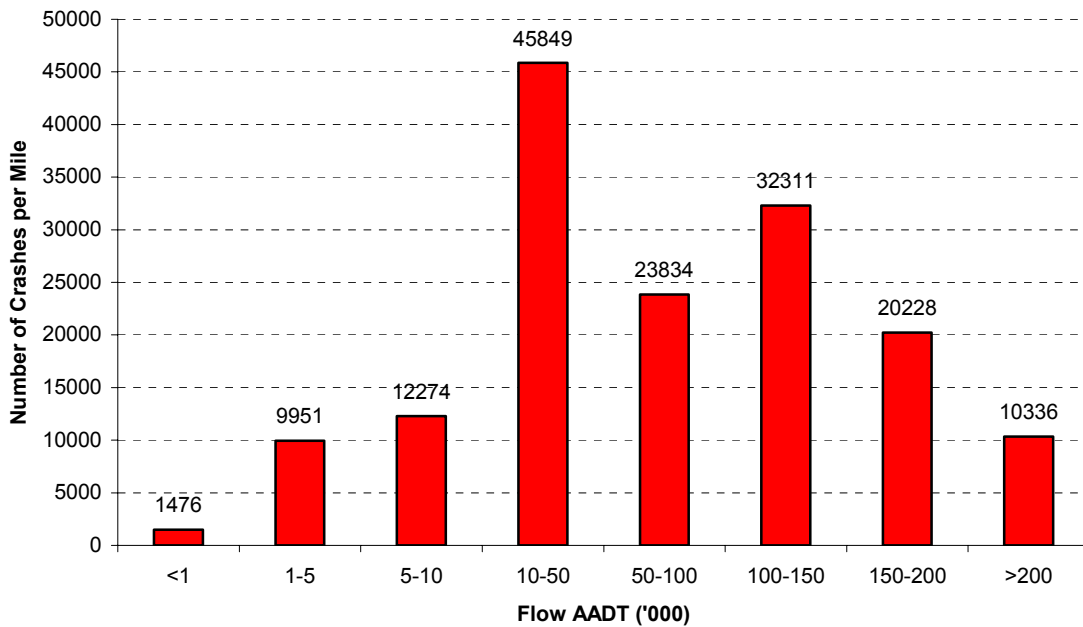


Figure A9. Relationship Between the Number of Crashes per Mile and Traffic Flow (1997-1999).

Figure A10 shows the number of crashes defined by the first harmful event for all and single-vehicle crashes respectively. According to the DPS, the first harmful event is defined as the first event that caused either an occupant to become injured or substantial damages to the vehicle. This field should not be mistaken with the most harmful event. The accident form and the DPS database do not contain such a field.

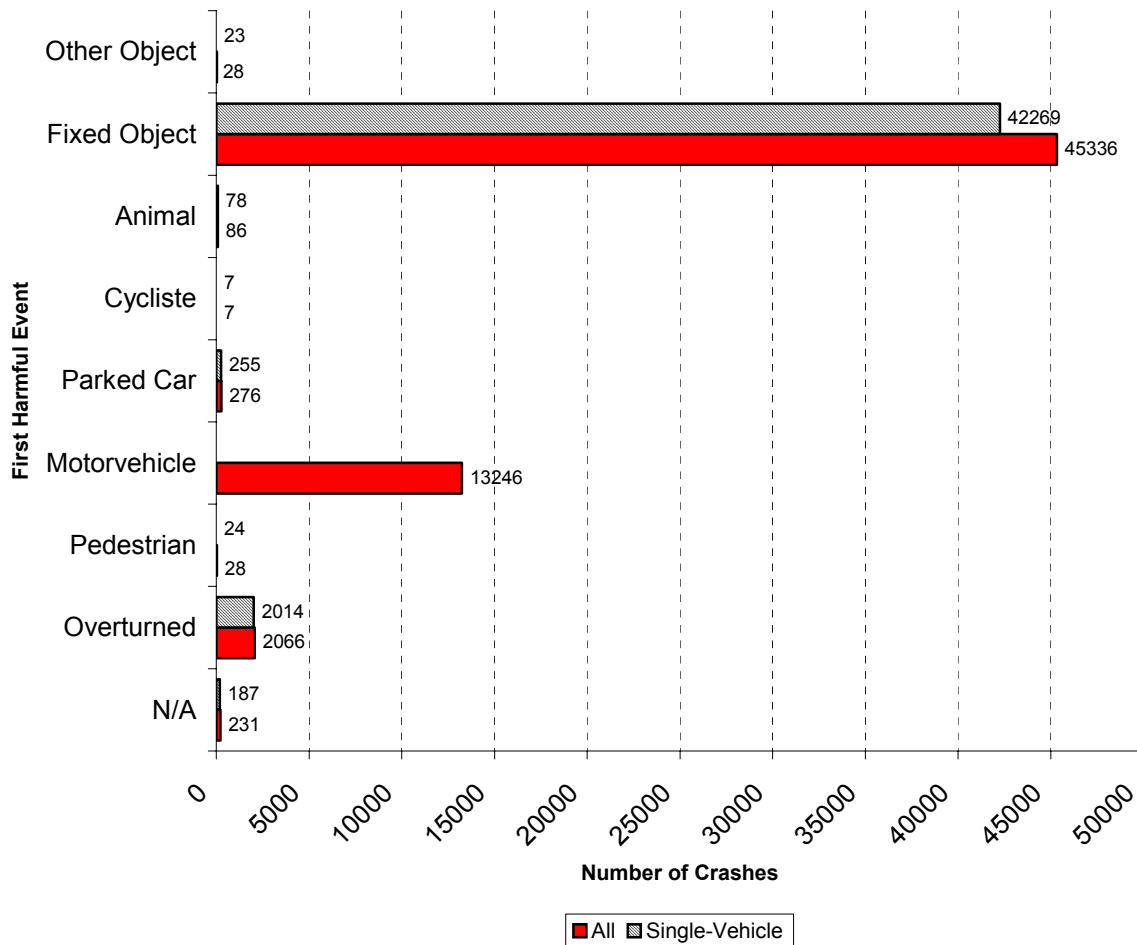


Figure A10. Number of Crashes defined by the First Harmful Event for All and Single-Vehicle Crashes (1997-1999).

Figure A10 shows that hitting one of the selected roadside objects is the most frequent first harmful event, followed by “hitting another vehicle” and “vehicle rolling over” respectively. For the latter event, most involved only one vehicle. As indicated above, in about 5 percent of single-vehicle crashes, the vehicle hit another object before striking one of the roadside safety features.

A3.2 Characteristics of Crash Data by Roadside Safety Features

This section summarizes the characteristics of the crash data for each roadside safety feature separately. The section shows where the crashes occur in Texas and the different severities associated with each feature.

Figure A11 exhibits the summary of the crash data for each feature. This figure reveals that median barriers, guardrails, and highway signs account for more than 70 percent of all roadside objects hit by a vehicle. However, these features are also the ones most often used on the TxDOT maintained highway system.

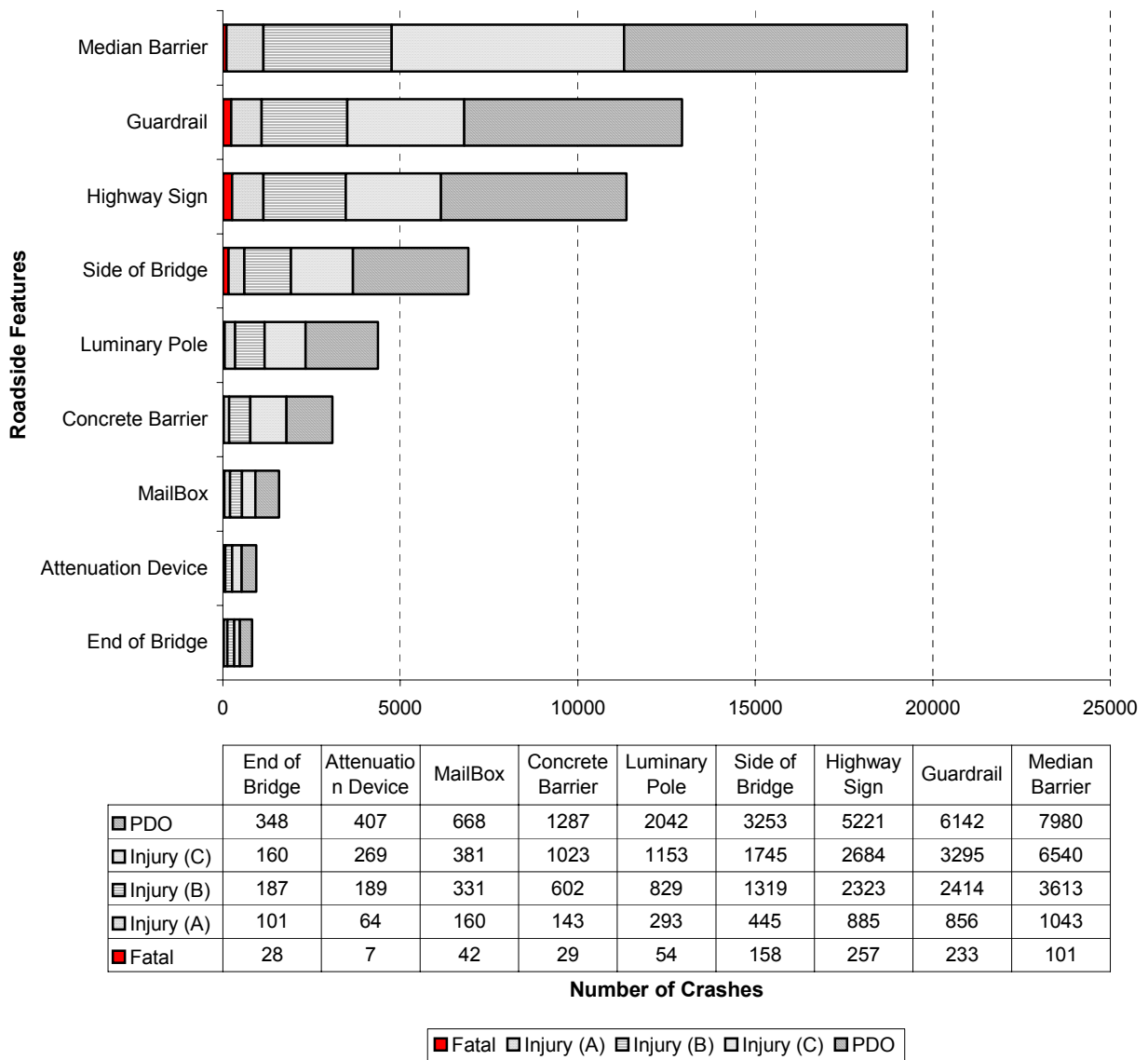


Figure A11. Number of Crashes by Roadside Feature (1997-1999).

Figure A12 displays the proportion of reported fatal and injury of types A and B (KAB) crashes for each roadside feature. This figure shows that end of bridges and mailboxes appear to cause more serious injuries than the other features. In fact, the proportion of KAB crashes is about 38 percent and 34 percent respectively. It should be noted that other factors such as side slopes or type of surface might contribute to the harmful event, in addition to hitting the object per se. As indicated above, the data shown in this figure do not include missing crash counts. Hence, the researchers point out that the numbers shown in Figure A12 should be interpreted with caution. It is likely the “true” percentages would be less than the ones reported in Figure A12.

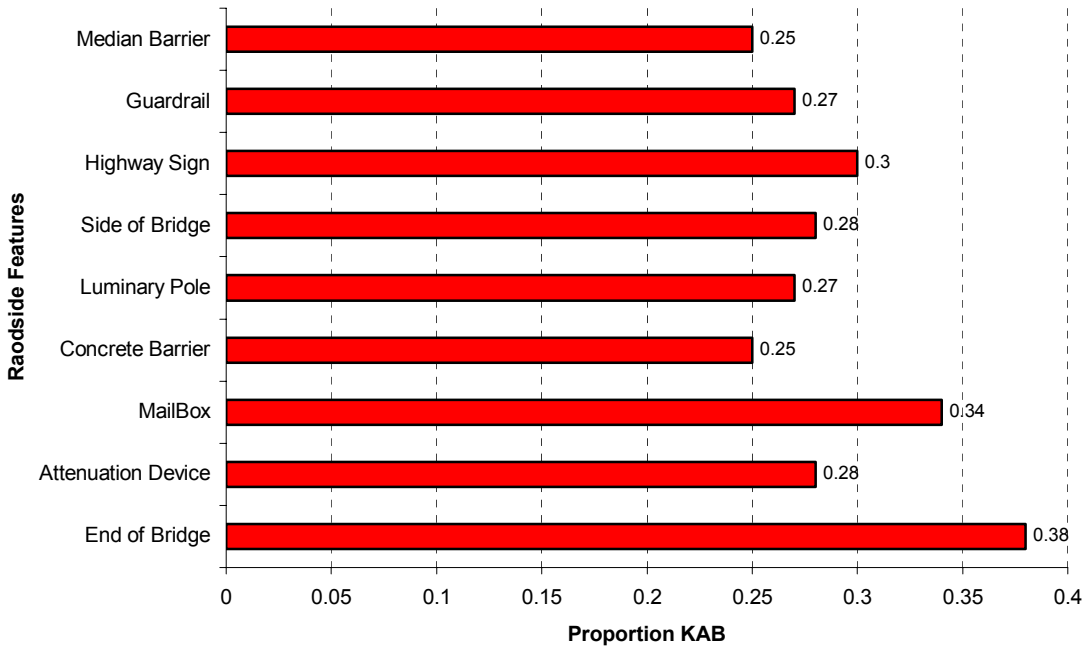


Figure A12. Proportion of KAB Crashes by Roadside Feature.

Highway Signs

Figure A13 and Table A4 show the distribution of crashes by county involving a highway sign by county and by TxDOT administrative district respectively. The data reveal that highway signs are, as expected, more frequently hit in Houston and Dallas districts.

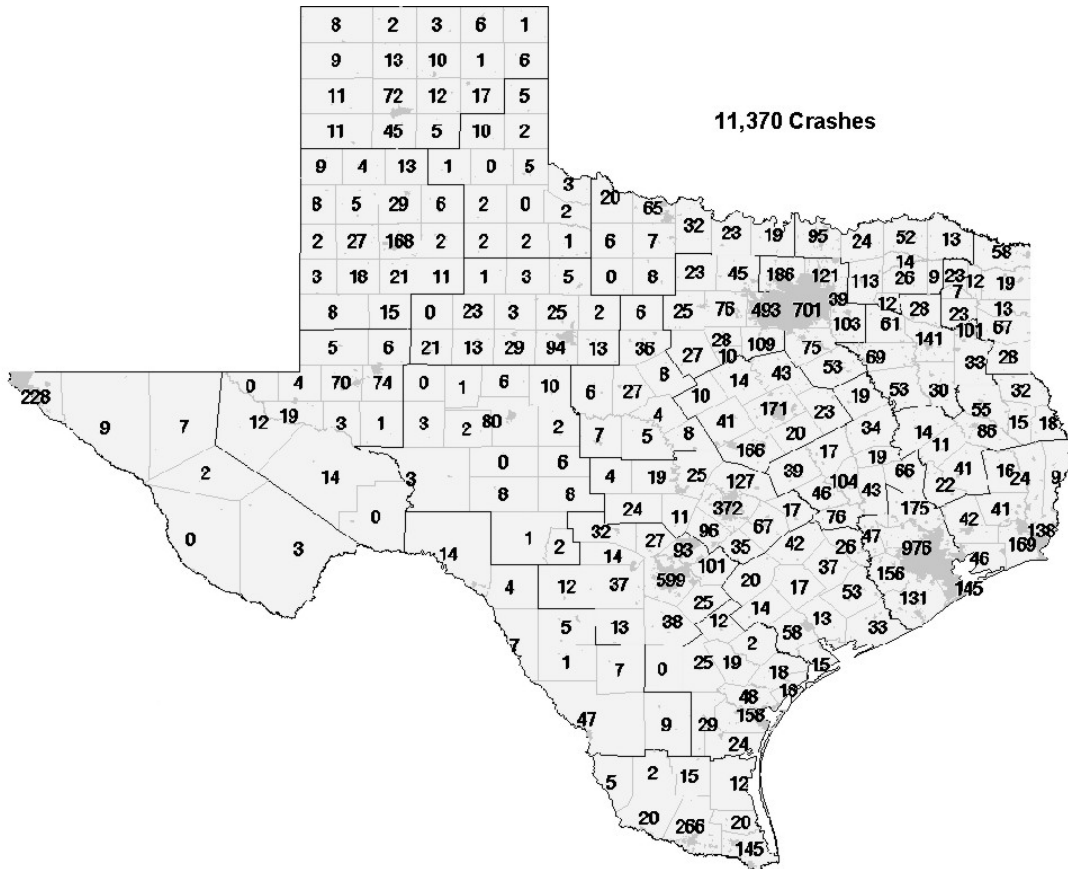


Figure A13. Number of Crashes Involving Highway Signs by County (1997-1999).

**Table A4. Number of Crashes Involving Highway Signs by TxDOT
Administrative District (1997-1999).**

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	8	43	80	91	136	358
Forth Worth	16	68	166	213	373	836
Wichita Falls	5	18	43	33	81	180
Amarillo	3	21	49	49	110	232
Lubbock	13	25	83	79	149	349
Odessa	6	21	37	53	91	208
San Angelo	1	15	35	27	54	132
Abilene	4	27	67	45	89	232
Waco	15	45	92	107	229	488
Tyler	10	48	129	111	218	516
Lufkin	9	32	59	55	139	294
Houston	32	115	266	447	770	1,630
Yoakum	9	22	78	73	146	328
Austin	18	60	172	148	399	797
San Antonio	11	76	165	240	499	991
Corpus Christi	17	29	64	90	153	353
Bryan	14	29	126	86	208	463
Dallas	26	73	274	310	595	1,278
Atlanta	4	20	56	58	112	250
Beaumont	9	38	85	109	244	485
Pharr	15	31	102	140	197	485
Laredo	2	8	15	23	46	94
Brownwood	3	12	21	29	42	107
El Paso	6	7	48	65	123	249
Childress	1	2	11	3	18	35
Total	257	885	2,323	2,684	5,221	11,370

Guardrails

Figure A14 and Table A5 show the distribution of crashes involving a guardrail by county and TxDOT administrative district, respectively. The figure shows that guardrails are hit more often in counties where interstate highways are located (e.g., I-35, I-10, etc.).

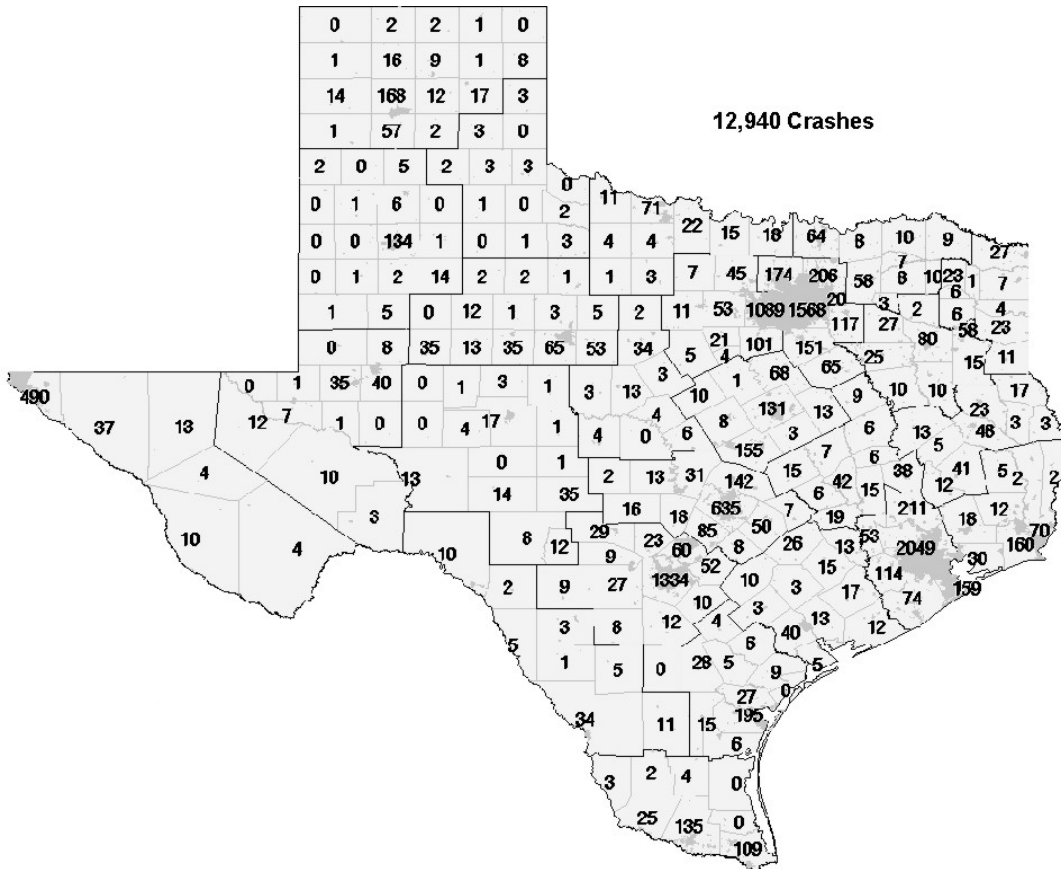


Figure A14. Number of Crashes Involving a Guardrail by County (1997-1999).

**Table A5. Number of Crashes Involving a Guardrail by TxDOT
Administrative District (1997-1999).**

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	3	16	43	31	84	177
Forth Worth	20	125	276	323	592	1,336
Wichita Falls	4	17	31	30	67	149
Amarillo	5	18	66	69	153	311
Lubbock	3	10	41	41	77	172
Odessa	5	13	22	30	47	117
San Angelo	5	12	29	17	47	110
Abilene	7	15	42	49	114	227
Waco	13	18	71	79	208	389
Tyler	7	18	45	54	103	227
Lufkin	9	12	41	28	75	165
Houston	38	150	444	785	1,242	2,659
Yoakum	3	4	41	41	68	157
Austin	16	56	187	225	523	1,007
San Antonio	25	68	260	403	818	1,574
Corpus Christi	4	17	50	64	160	295
Bryan	1	15	28	33	86	163
Dallas	39	172	446	626	1,018	2,301
Atlanta	3	9	22	24	50	108
Beaumont	6	21	66	74	132	299
Pharr	3	24	49	77	125	278
Laredo	2	5	10	17	37	71
Brownwood	2	7	12	14	34	69
El Paso	10	33	88	155	272	558
Childress	0	1	4	6	10	21
Total	233	856	2,414	3,295	6,142	12,940

Luminary Poles

Figure A15 and Table A6 illustrate the distribution of crashes involving a luminary pole by county and TxDOT administrative district respectively. Similarly to guardrails, luminary poles are hit more frequently along major highway corridors.

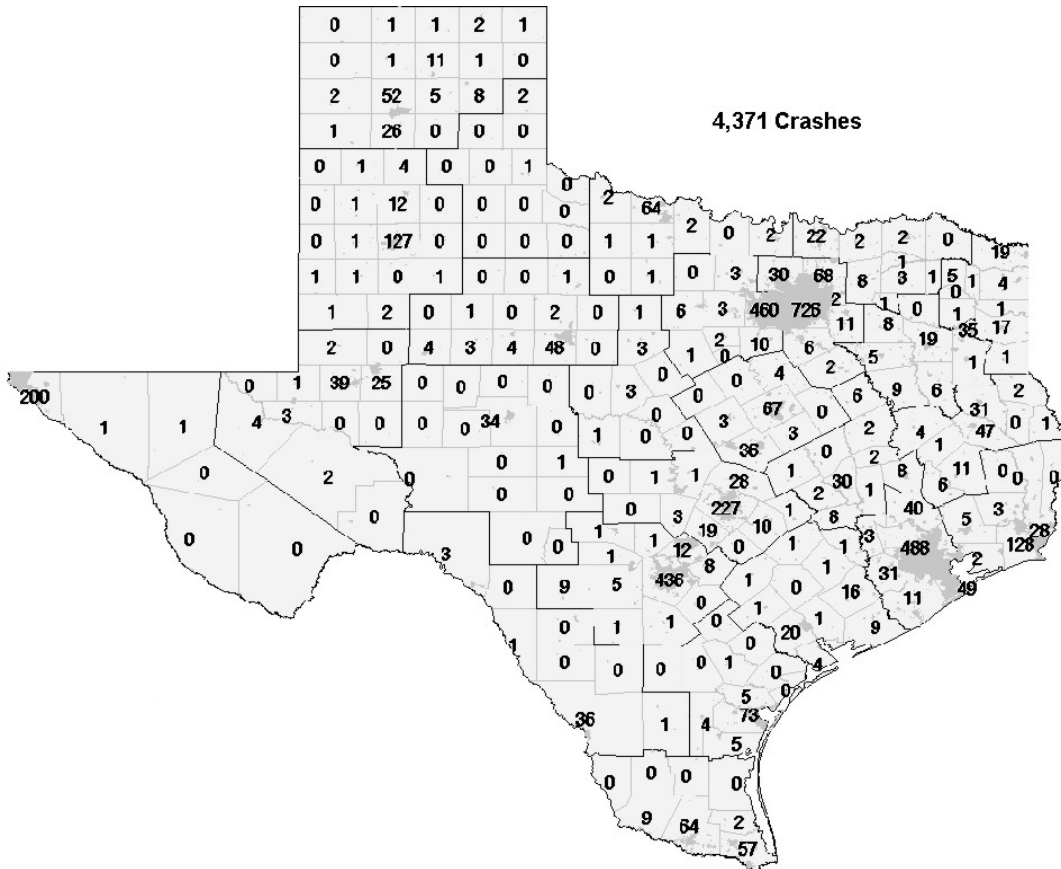


Figure A15. Number of Crashes Involving a Luminary Pole by County (1997-1999).

Table A6. Number of Crashes Involving a Luminary Pole by TxDOT Administrative District (1997-1999).

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	0	5	13	5	17	40
Forth Worth	1	40	96	101	247	485
Wichita Falls	0	2	18	19	34	73
Amarillo	2	8	20	25	57	112
Lubbock	2	11	29	38	72	152
Odessa	3	3	23	21	26	76
San Angelo	0	3	7	8	17	35
Abilene	3	4	15	19	22	63
Waco	1	9	23	25	55	113
Tyler	0	6	16	24	37	83
Lufkin	1	7	17	21	57	103
Houston	9	57	113	217	226	622
Yoakum	2	5	10	16	22	55
Austin	3	18	57	53	159	290
San Antonio	4	26	69	125	251	475
Corpus Christi	1	8	17	22	40	88
Bryan	0	7	11	11	31	60
Dallas	10	49	166	235	385	845
Atlanta	1	4	14	11	19	49
Beaumont	3	7	28	35	93	166
Pharr	2	3	21	41	65	132
Laredo	0	1	8	17	15	41
Brownwood	0	1	3	1	3	8
El Paso	6	8	34	62	92	202
Childress	0	1	1	1	0	3
Total	54	293	829	1,153	2,042	4,371

Mailboxes

Figure A16 and Table A7 show the distribution of crashes involving a mailbox by county and TxDOT administrative district respectively. Mailboxes are hit more often in counties located in Eastern Texas.

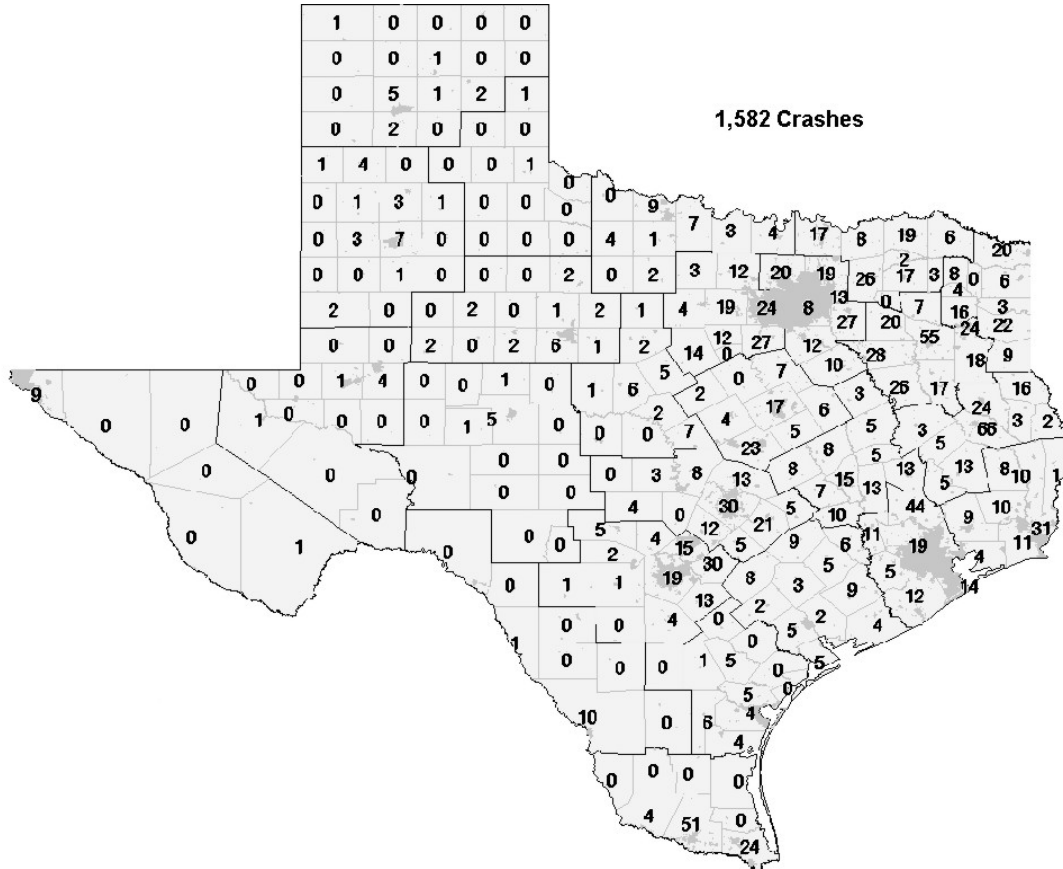


Figure A16. Number of Crashes Involving a Mailbox by County (1997-1999).

**Table A7. Number of Crashes Involving a Mailbox by TxDOT
Administrative District (1997-1999).**

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	4	10	22	32	30	98
Forth Worth	3	13	24	20	55	115
Wichita Falls	1	8	6	4	11	30
Amarillo	0	2	1	2	7	12
Lubbock	0	2	5	3	13	23
Odessa	0	0	0	0	6	6
San Angelo	0	0	0	1	6	7
Abilene	2	4	4	5	3	18
Waco	3	9	15	6	31	64
Tyler	7	17	35	51	85	195
Lufkin	4	18	37	32	46	137
Houston	3	9	23	29	41	105
Yoakum	0	3	16	17	22	58
Austin	2	11	27	17	44	101
San Antonio	2	8	23	23	38	94
Corpus Christi	1	1	6	10	7	25
Bryan	3	9	14	16	45	87
Dallas	1	7	23	27	51	109
Atlanta	1	9	16	21	41	88
Beaumont	1	8	19	23	33	84
Pharr	2	7	10	28	32	79
Laredo	0	0	0	6	5	11
Brownwood	1	5	4	5	9	24
El Paso	1	0	0	3	6	10
Childress	0	0	1	0	1	2
Total	42	160	331	381	668	1,582

Median Barriers

Figure A17 and Table A8 illustrate the distribution of crashes involving a median barrier by county and TxDOT administrative district, respectively. The figure shows that median barriers are hit more frequently, as expected, along interstate and freeway corridors.

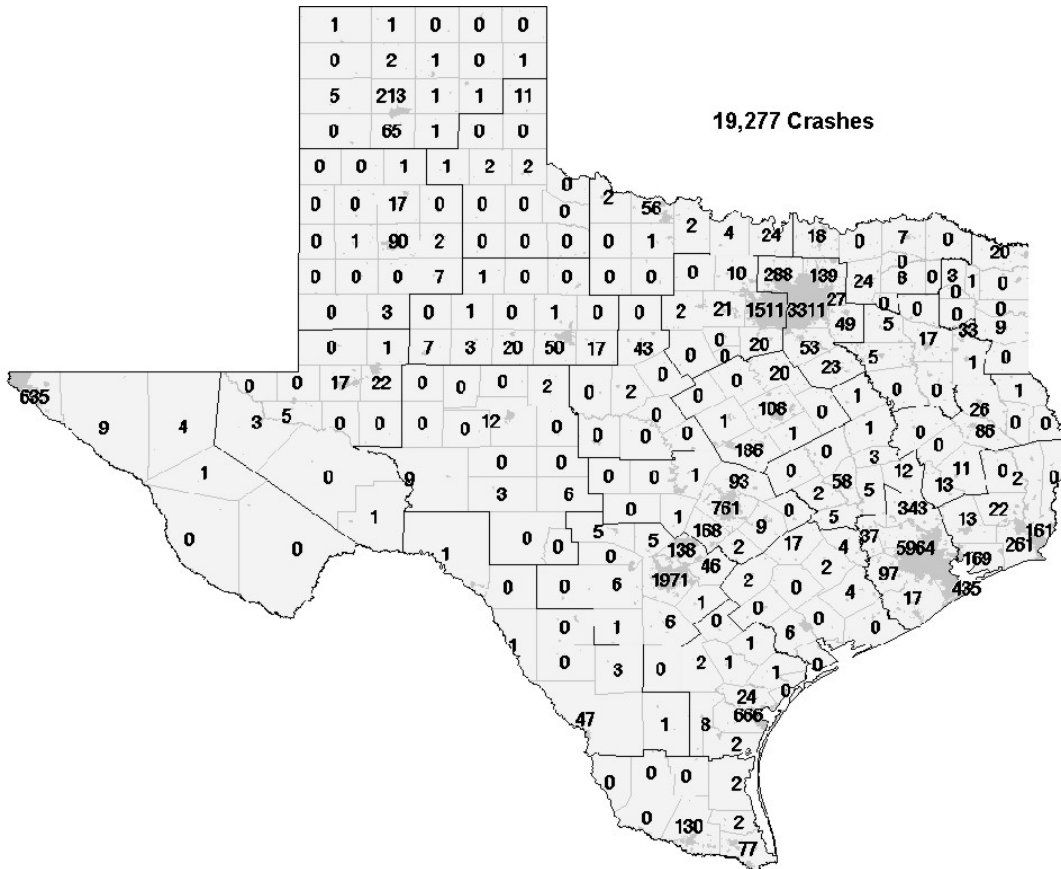


Figure A17. Number of Crashes Involving a Median Barrier by County (1997-1999).

**Table A8. Number of Crashes Involving a Median Barrier by TxDOT
Administrative District (1997-1999).**

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	0	5	14	13	25	57
Forth Worth	7	152	381	445	579	1,564
Wichita Falls	2	5	25	11	46	89
Amarillo	1	16	40	71	164	292
Lubbock	1	10	26	40	44	121
Odessa	1	1	14	13	20	49
San Angelo	1	3	6	7	15	32
Abilene	2	5	22	21	50	100
Waco	4	15	63	84	150	316
Tyler	0	2	11	10	39	62
Lufkin	2	10	19	34	72	137
Houston	33	337	1,121	2,578	2,824	6,893
Yoakum	0	2	4	7	22	35
Austin	4	65	251	245	470	1,035
San Antonio	8	104	332	708	1027	2,179
Corpus Christi	2	33	143	250	277	705
Bryan	0	3	14	29	41	87
Dallas	25	203	845	1,488	1,329	3,890
Atlanta	0	3	8	3	18	32
Beaumont	4	30	108	179	307	628
Pharr	3	13	42	62	91	211
Laredo	0	3	7	16	27	53
Brownwood	0	1	5	11	28	45
El Paso	1	19	110	214	305	649
Childress	0	3	2	1	10	16
Total	101	1,043	3,613	6,540	7,980	19,277

End of a Bridge

Figure A18 and Table A9 illustrate the distribution of crashes involving the end of a bridge by county and TxDOT administrative district respectively. The end of a bridge is hit more frequently in Eastern Texas.

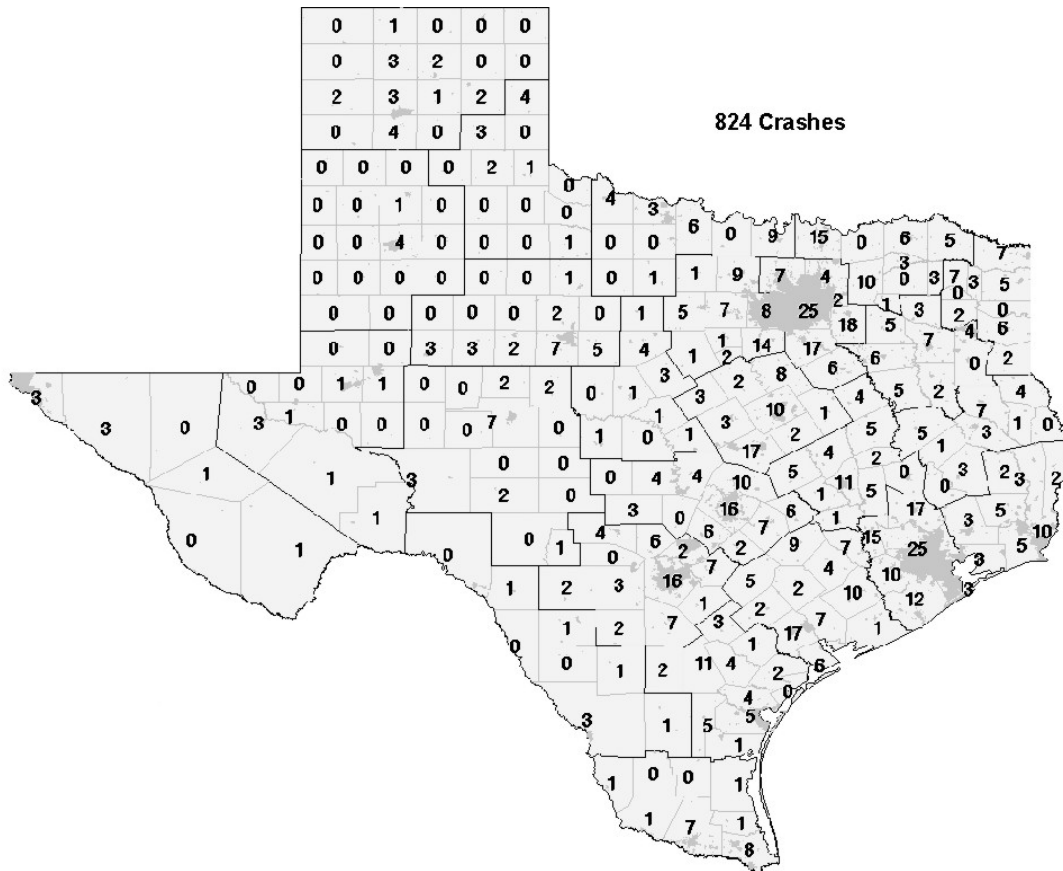


Figure A18. Number of Crashes Involving the End of a Bridge by County (1997-1999).

Table A9. Number of Crashes Involving the End of a Bridge by TxDOT Administrative District (1997-1999).

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	1	4	14	13	11	43
Forth Worth	1	8	11	9	19	48
Wichita Falls	1	0	8	6	8	23
Amarillo	0	4	3	2	9	18
Lubbock	0	0	1	0	4	5
Odessa	2	1	2	0	3	8
San Angelo	1	4	6	3	3	17
Abilene	1	2	6	4	10	23
Waco	0	4	13	8	21	46
Tyler	1	6	7	2	15	31
Lufkin	1	4	4	4	11	24
Houston	0	8	12	20	42	82
Yoakum	3	9	14	18	26	70
Austin	0	8	13	6	31	58
San Antonio	0	7	13	17	15	52
Corpus Christi	3	6	9	6	12	36
Bryan	1	4	10	6	18	39
Dallas	5	11	16	12	35	79
Atlanta	4	1	8	6	13	32
Beaumont	3	3	7	2	18	33
Pharr	0	1	2	8	8	19
Laredo	0	2	0	2	3	7
Brownwood	0	1	3	3	5	12
El Paso	0	1	1	2	4	8
Childress	0	2	4	1	4	11
Total	28	101	187	160	348	824

Side of a Bridge

Figure A19 and Table A10 show the distribution of crashes involving the side of a bridge by county and TxDOT administrative district, respectively. The data show that vehicles hit the side of a bridge more frequently in counties located in Eastern Texas and along interstate and freeway corridors. This can be the result of a variety of reasons such as geometric layout at bridges, roadside safety features used at bridges in other areas of the state, etc.

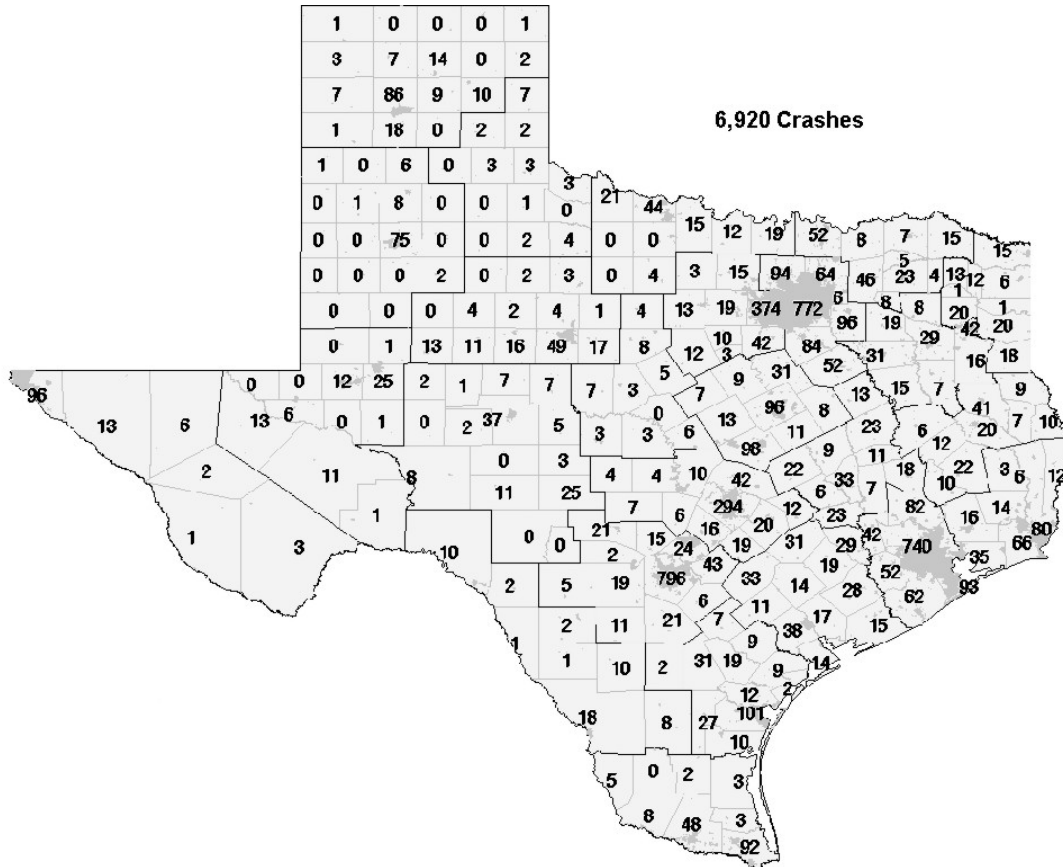


Figure A19. Number of Crashes Involving the Side of a Bridge by County (1997-1999).

Table A10. Number of Crashes Involving the Side of a Bridge by TxDOT Administrative District (1997-1999).

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	7	22	40	19	80	168
Forth Worth	15	40	90	126	220	491
Wichita Falls	3	11	20	19	62	115
Amarillo	2	11	25	34	87	159
Lubbock	0	4	17	20	52	93
Odessa	2	7	11	15	35	70
San Angelo	2	6	29	22	49	108
Abilene	4	14	32	22	50	122
Waco	8	19	47	59	140	273
Tyler	6	13	25	38	87	169
Lufkin	0	8	26	34	68	136
Houston	26	65	179	320	478	1,068
Yoakum	7	14	59	54	116	250
Austin	7	26	77	85	238	433
San Antonio	16	41	161	276	472	966
Corpus Christi	9	11	46	57	104	227
Bryan	5	6	34	38	85	168
Dallas	23	78	234	330	502	1,167
Atlanta	2	5	29	22	47	105
Beaumont	5	19	50	55	103	232
Pharr	3	7	42	40	69	161
Laredo	3	3	7	20	19	52
Brownwood	1	5	9	6	18	39
El Paso	1	8	24	31	57	121
Childress	1	2	6	3	15	27
Total	158	445	1,319	1,745	3,253	6,920

Attenuation Devices

Figure A20 and Table A11 show the distribution of crashes involving an attenuation device by county and TxDOT administrative district, respectively. The figure and the table show that more than 78 percent of attenuation devices are struck in Dallas-Fort Worth, Houston, San Antonio, and Houston areas.

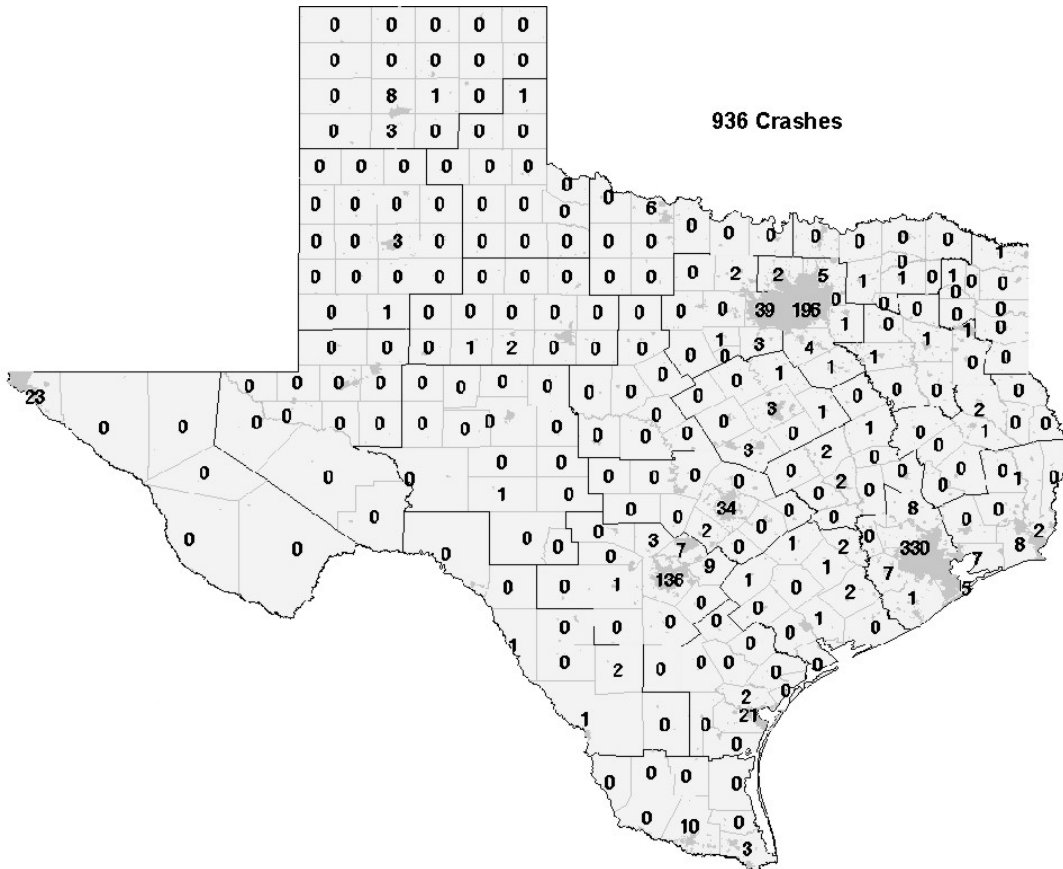


Figure A20. Number of Crashes Involving an Attenuation Device by County (1997-1999).

Table A11. Number of Crashes Involving an Attenuation Device by TxDOT Administrative District (1997-1999).

	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	0	0	0	0	2	2
Forth Worth	0	5	8	13	19	45
Wichita Falls	0	0	2	2	2	6
Amarillo	0	0	2	6	4	12
Lubbock	0	0	1	2	1	4
Odessa	0	0	0	0	0	0
San Angelo	0	1	0	0	0	1
Arlene	0	0	1	0	2	3
Waco	0	1	1	2	4	8
Tyler	0	1	0	2	0	3
Lufkin	0	1	0	1	1	3
Houston	1	22	69	117	142	351
Yoakum	0	0	5	0	3	8
Austin	0	2	12	8	14	36
San Antonio	1	15	25	40	75	156
Corpus Christi	1	2	5	8	7	23
Bryan	0	1	1	1	2	5
Dallas	4	9	46	51	99	209
Atlanta	0	0	0	0	2	2
Beaumont	0	2	3	5	8	18
Pharr	0	1	1	2	9	13
Laredo	0	0	0	3	1	4
Brownwood	0	0	0	0	0	0
El Paso	0	1	6	6	10	23
Childress	0	0	1	0	0	1
Total	7	64	189	269	407	936

Table A12. Number of Crashes Involving a Concrete Barrier by TxDOT Administrative District (1997-1999).

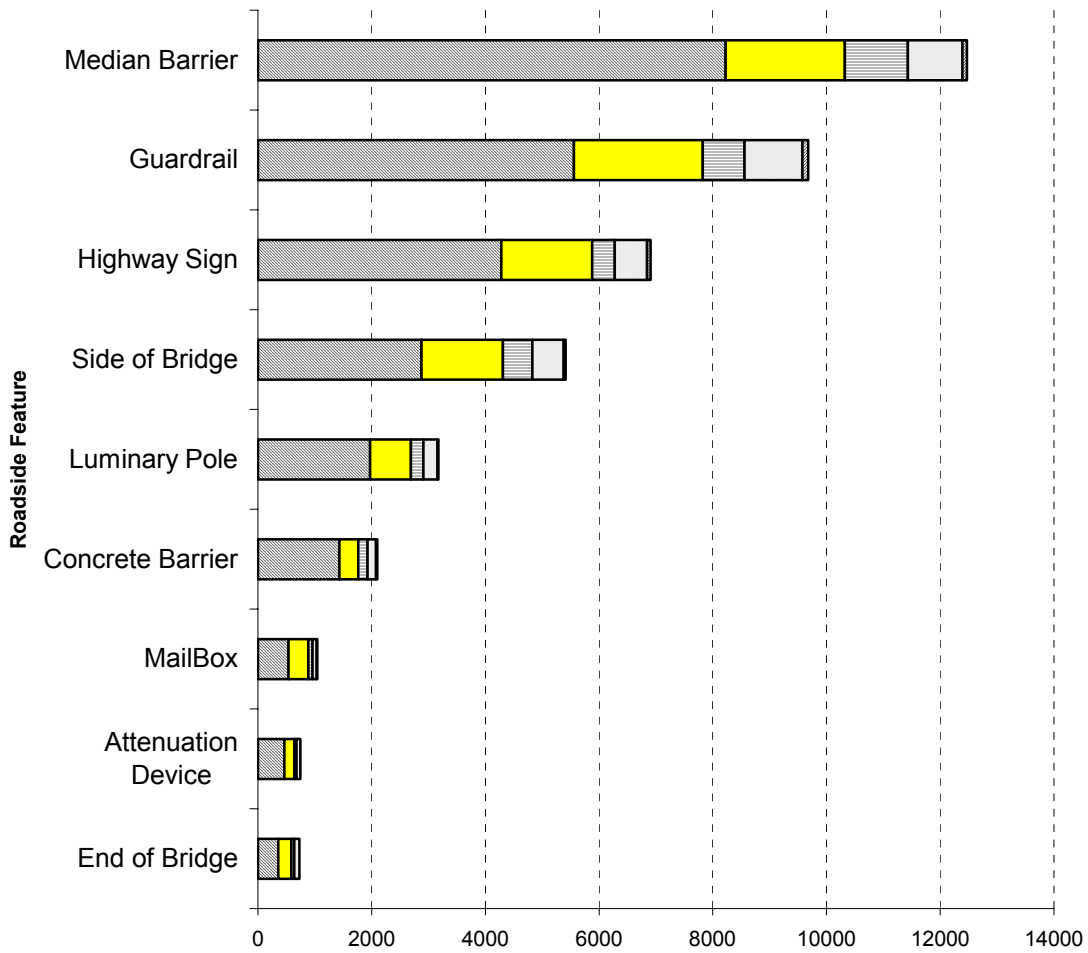
	Fatal	Injury (A)	Injury (B)	Injury (C)	PDO	Total
Paris	0	0	1	1	0	2
Forth Worth	2	11	39	46	49	147
Wichita Falls	0	1	3	1	6	11
Amarillo	0	3	3	4	12	22
Lubbock	0	4	2	6	10	22
Odessa	0	0	2	4	6	12
San Angelo	0	0	0	1	0	1
Arlene	0	1	2	3	8	14
Waco	0	2	3	2	14	21
Tyler	1	1	1	2	5	10
Lufkin	0	0	1	3	2	6
Houston	14	66	276	526	575	1,457
Yoakum	0	1	1	2	2	6
Austin	0	4	19	20	63	106
San Antonio	3	16	70	165	221	475
Corpus Christi	1	4	24	30	43	102
Bryan	0	0	6	1	3	10
Dallas	6	22	109	137	174	448
Atlanta	0	0	0	2	1	3
Beaumont	1	1	9	20	13	44
Pharr	0	2	5	12	16	35
Laredo	0	0	2	0	7	9
Brownwood	0	0	0	0	0	0
El Paso	1	4	24	35	56	120
Childress	0	0	0	0	1	1
Total	29	143	602	1,023	1,287	3,084

A3.3 Characteristics of Crash Data by Vehicle Type

This section summarizes the characteristics of crashes by vehicle type. The analysis carried out in this section includes only reported single-vehicle crashes. There were 42,269 single-vehicle crashes involving a roadside feature between 1997 and 1999 inclusively. The vehicle types were grouped under five categories, as defined by DPS:

- 1) Passenger cars (P.C.),
- 2) Pickup trucks,
- 3) Sport utility vehicles (SUV),
- 4) Large trucks (3 axles or more), and
- 5) Others (car and a trailer, etc.).

[Figure A22](#) and [Table A13](#) exhibit the number of crashes by vehicle type for each roadside feature. The figure shows that 60 percent (25,721) of the roadside objects struck involve a passenger car. Pickup trucks and SUV vehicles account for 30 percent of all crashes (12,493).



	End of Bridge	Attenuation Device	MailBox	Concrete Barrier	Luminary Pole	Side of Bridge	Highway Sign	Guardrail	Median Barrier
Other	0	4	14	18	16	36	59	103	76
Large Truck	92	67	71	154	243	552	572	1016	962
SUV	51	41	75	161	220	512	399	736	1107
Pickup	226	173	348	333	720	1436	1592	2263	2100
Passenger Car	362	465	539	1434	1974	2877	4284	5560	8226

Number of Crashes

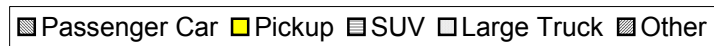


Figure A22. Number of Crashes by Vehicle Type for Each Feature (1997-1999).

Table A13. Proportion of Crashes (percent) by Vehicle Type for Each Roadside Feature (1997-1999).

	Passenger Car	Pickup	SUV	Large Truck	Other	Total	Total Crashes
Median Barrier	49.5	30.9	7.0	12.6	0.0	100.0	12,471
Guardrail	62.0	23.1	5.5	8.9	0.5	100.0	9,678
Highway Sign	51.5	33.2	7.2	6.8	1.3	100.0	6,906
Side of Bridge	68.3	15.9	7.7	7.3	0.9	100.0	5,413
Luminary Pole	62.2	22.7	6.9	7.7	0.5	100.0	3,173
Concrete Barrier	53.1	26.5	9.5	10.2	0.7	100.0	2,100
MailBox	62.0	23.1	5.8	8.3	0.9	100.0	1,047
Attenuation Device	57.4	23.4	7.6	10.5	1.1	100.0	750
End of Bridge	66.0	16.8	8.9	7.7	0.6	100.0	731
Average	60.9	21.7	7.8	8.8	0.8	100.0	--
Total Crashes	25,721	9,191	3,302	3,729	326	--	42,269

Table A13 illustrates that large trucks hit guardrails, mailboxes, and concrete barriers proportionally more often than passenger cars. However, the higher percentage of large truck involvement may partly be explained by the greater likelihood of under-reported crashes involving passenger cars, pickup trucks, and SUV vehicles.

Passenger Cars

Figure A23 shows the number of single-vehicle crashes involving a passenger car by severity for each roadside feature. The figure exhibits that about 22 percent of all crashes are categorized as KAB. The probability of being fatally or severely injured in a crash is much higher when a passenger car hits the end of a bridge. Results from the analysis indicate that the probability in Texas based on the data for 1997 to 1999 is higher than 37 percent.

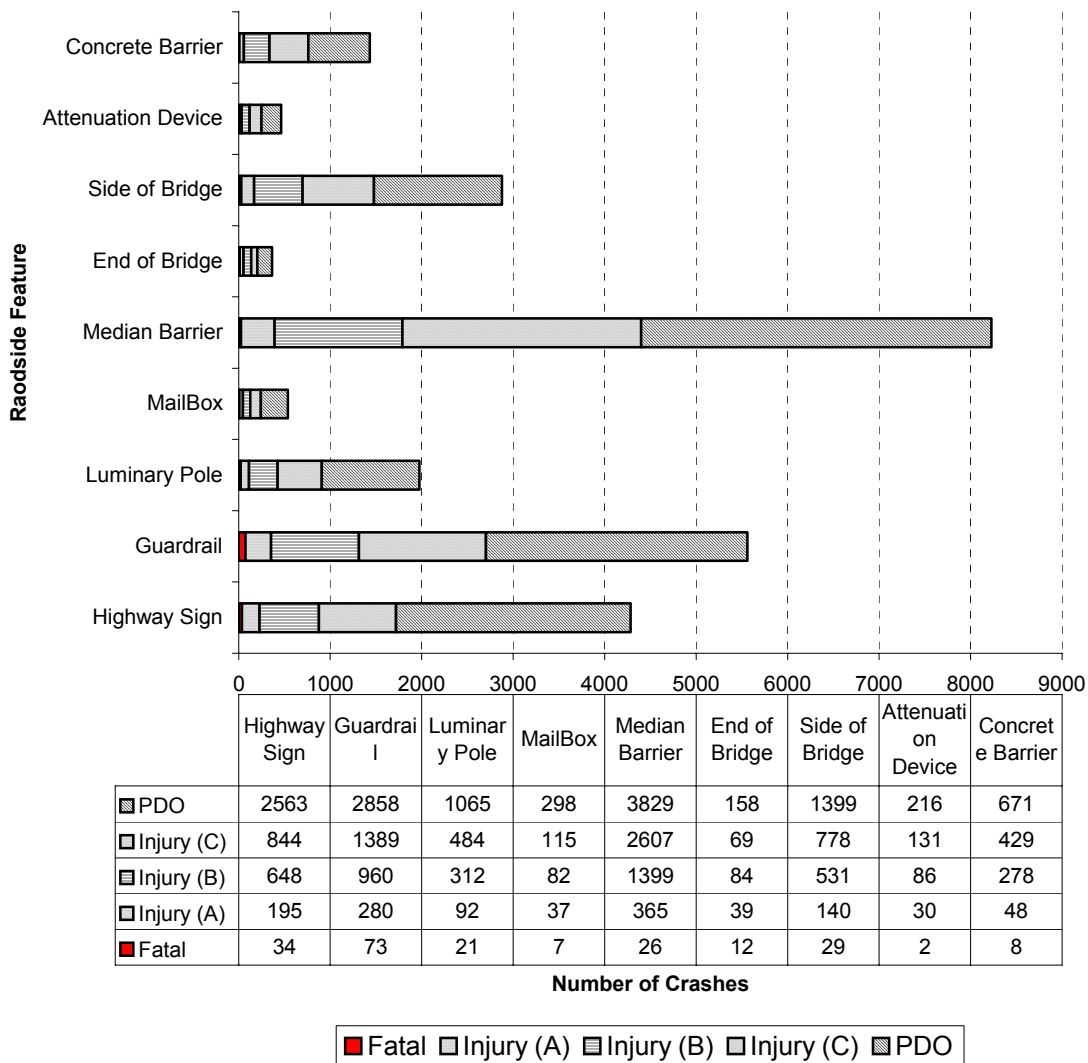


Figure A23. Number of Single-Vehicle Crashes Involving a Passenger Car by Severity (1997-1999).

Pickup Trucks

Figure A24 illustrates the number of single-vehicle crashes involving a pickup truck by severity for each roadside feature. In this figure, about 24 percent of crashes are categorized as KAB. The probability of severe injuries is relatively higher for mailboxes and end of bridges for this category of vehicles.

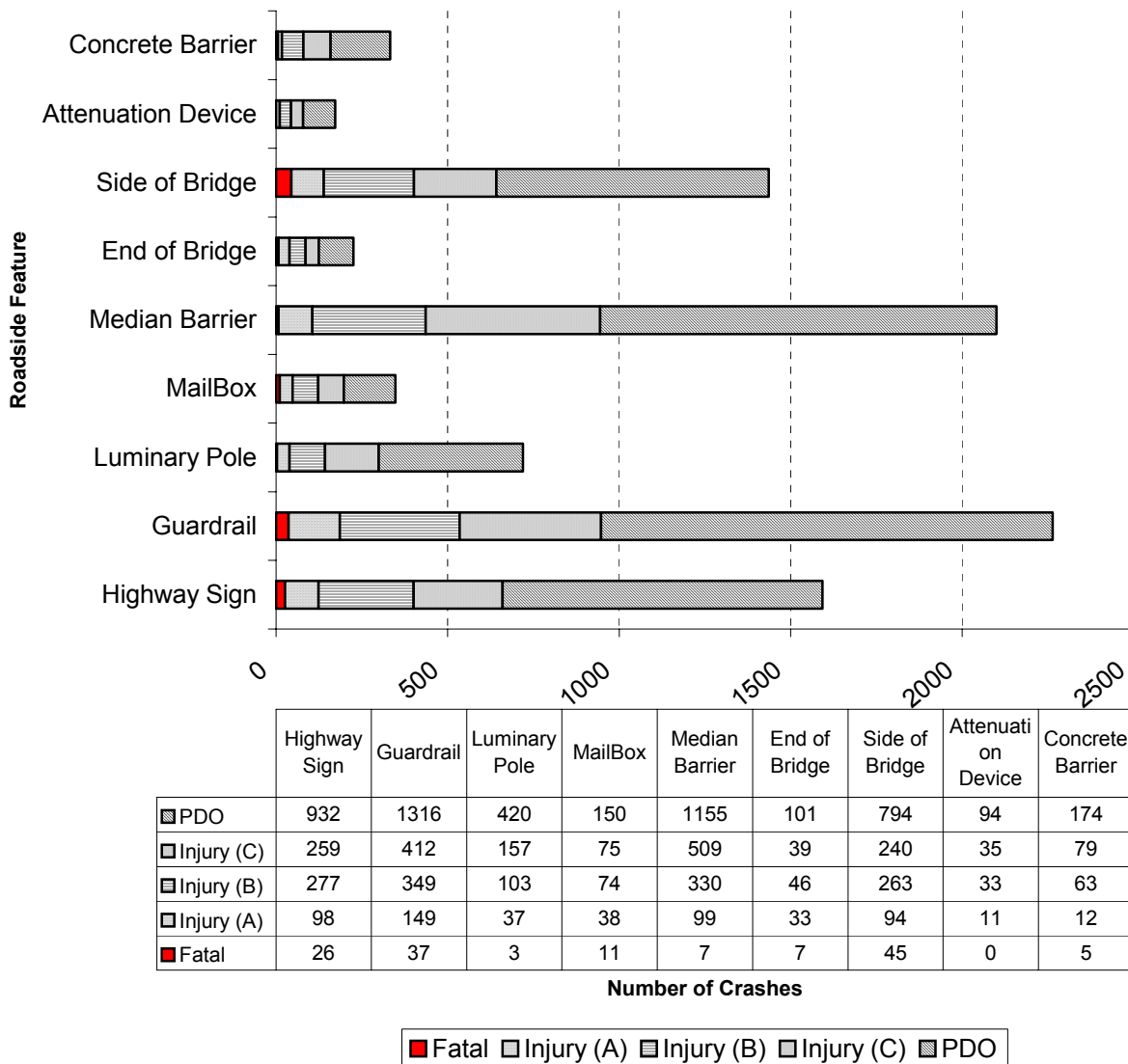


Figure A24. Number of Single-Vehicle Crashes Involving a Pickup Truck by Severity (1997-1999).

Sport Utility Vehicles

Figure A25 exhibits the number of single-vehicle crashes involving an SUV vehicle for each roadside feature. This figure reveals that about 30 percent of crashes are categorized as KAB, which is 8 percent higher than passenger cars. Interestingly, drivers have a 50 percent chance of being severely injured if they hit the end of a bridge when driving an SUV.

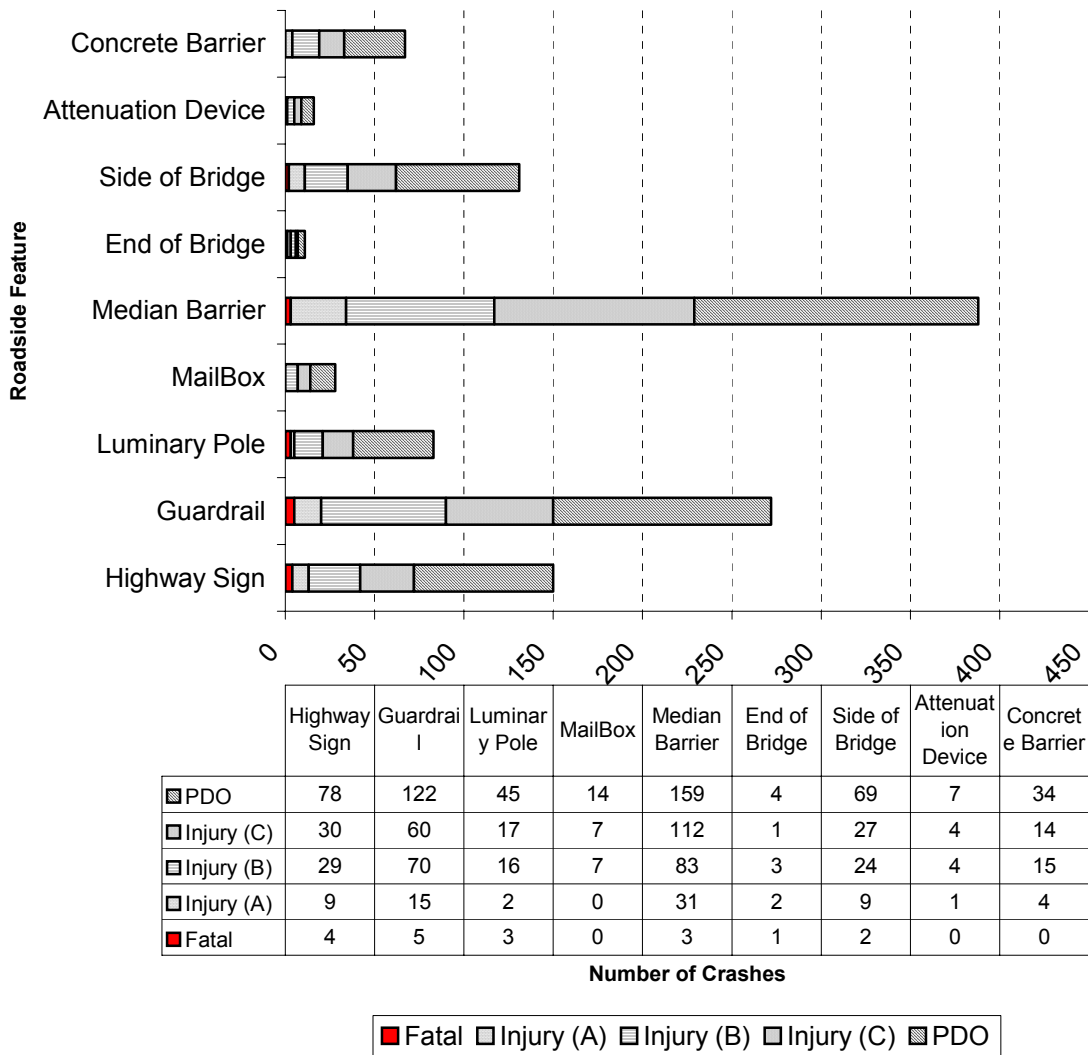


Figure A25. Number of Single-Vehicle Crashes Involving an SUV by Severity (1997-1999).

Large Trucks

Figure A26 shows the number of single-vehicle crashes involving a large truck for each roadside feature. This figure demonstrates that more than 45 percent of large truck-related crashes are either fatal or very severe. A truck driver has more than 60 percent chance of being involved in an KAB crash when either a mailbox or an end of bridge is hit. In addition, the data shows that very few crashes lead to minor injuries (type C). The crash data tend to indicate that roadside features fail more frequently when a large truck is involved in a collision.

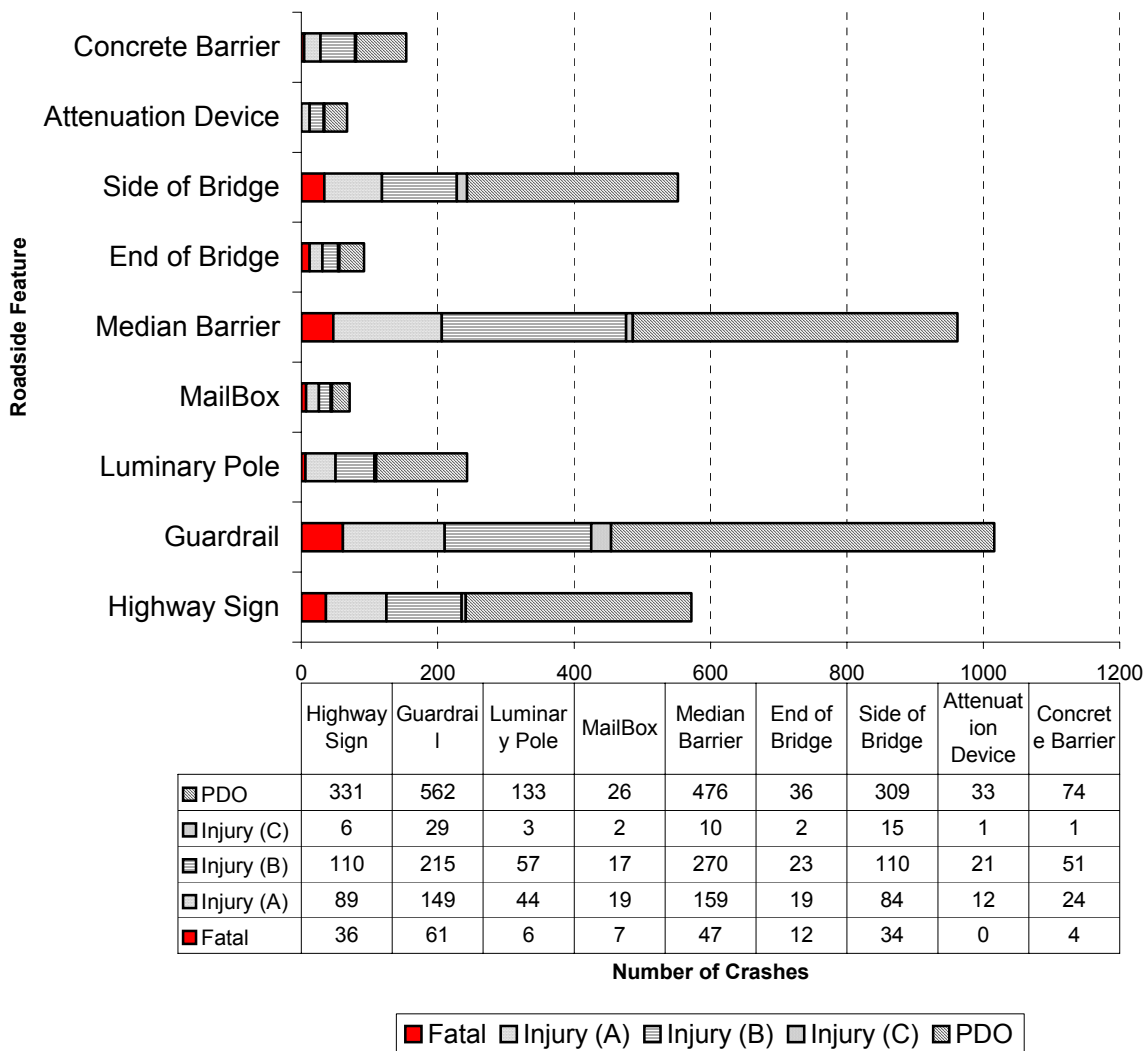


Figure A26. Number of Single-Vehicle Crashes Involving a Large Truck by Severity (1997-1999).

A4. SUMMARY AND CONCLUSIONS

As part of the planning process for the ISPE pilot test, researchers analyzed three years of crash data related to roadside safety features. The devices selected for analyses were selected jointly by the research panel and the research team. The selected features were highway signs, guardrails, luminary poles, mailboxes, median barriers, bridge ends, sides of bridges, attenuation devices, and concrete barriers, respectively. On an annual basis, there are about 20,000 reported crashes involving one of the roadside devices on state maintained highways.

The results of the exploratory analysis performed in this task are bounded by two important limitations. First, the number of under-reporting crashes is currently unknown. The research team recommends that the statistics presented in this report be interpreted with caution. Second, the exploratory analysis was carried out with the roadside objects as defined by DPS, which may not meet the same definition as the one used by TxDOT (e.g., a guardrail could still be located in the median). In addition, there exist many different types of safety features within each category presented in this analysis (e.g., within the category of end treatments systems such as the ET2000, BEST, etc. are included). Unfortunately, it was not possible to conduct additional analyses for different types of safety features as only the main categories of devices are recorded on the accident report form.

The exploratory analysis of the crash data showed that median barriers, guardrails, and highway signs are the objects most often hit by errant vehicles. These three devices account for about 70 percent all reported crashes. This fact is not surprising since these devices are also the ones most often used by TxDOT. The proportion of fatal and severe collisions (KAB accident severity categories) for each object varied from 25 percent to 38 percent. End of bridges and mailboxes have the highest proportions of KAB crashes with 38 percent and 34 percent, respectively. The percentages do not include crashes not reported to DPS. Hence, all the percentages are likely to be lower than the ones presented in this report.

The results of the study have revealed that more than two-thirds of all crashes occur in the largest TxDOT administrative districts: Houston, Dallas, Fort Worth, San Antonio, and Austin. On the other hand, a substantially high number of counties, primarily located in Western Texas, have less than five crashes in a 3-year period. It is estimated that about 70 percent of crashes happen either on interstates or urban freeways. Similarly, above 88 percent of crashes occur on tangent road sections. Finally, three-fourths of crashes involve only a single-vehicle.

Passenger cars, pickup trucks, SUV vehicles, and large trucks account for 60 percent, 22 percent, 8 percent, and 9 percent of single-vehicle crashes, respectively. The data seem to indicate that the probability of being fatally or severely injured is the lowest for passenger cars and the highest for large trucks. In fact, a truck driver has half the chance of becoming severely or fatally injured when the truck collides with the end of a bridge. Roadside safety features failed more frequently when large trucks are involved in the collision.

Despite the limitations of the data analysis, the statistics offered in this report provide a good indication about the issues related to crashes involving the selected roadside safety features. It also presents the most important factors that are needed to carry out the subsequent tasks of the In-Service Performance Evaluation of Roadside Safety Features project.

**APPENDIX B:
ISPE SITE INSPECTION FORMS FOR PHASE I**

Claim number:

PHASE IA :
GUARDRAILS, END-TREATMENTS, IMPACT ATTENUATORS AND TRANSITIONS

Whenever possible, attach photographs and accident report form

1. SELECT THE TYPE OF DEVICE:

a) *GUARDRAIL SYSTEMS*

Post type:	<input type="checkbox"/>	ROUND WOODEN	<input type="checkbox"/>	STEEL POST
	<input type="checkbox"/>	RECTANGULAR WOOD		
Blockout type:	<input type="checkbox"/>	OTHER:		
	<input type="checkbox"/>	NONE	<input type="checkbox"/>	STEEL
	<input type="checkbox"/>	WOOD	<input type="checkbox"/>	PLASTIC
	<input type="checkbox"/>	OTHER:		
Foundation type:	<input type="checkbox"/>	CONCRETE	<input type="checkbox"/>	ASPHALT
	<input type="checkbox"/>			DIRT
	<input type="checkbox"/>	OTHER:		

b) *END TREATMENTS/ TERMINALS*

Type of device:	<input type="checkbox"/>	ET 2000 (& +)	<input type="checkbox"/>	SKT 350
	<input type="checkbox"/>	BEST	<input type="checkbox"/>	TURNUED DOWN
	<input type="checkbox"/>	OTHER:		

c) *IMPACT ATTENUATORS*

Type of device:	<input type="checkbox"/>	GREAT	<input type="checkbox"/>	HEXFOAM
	<input type="checkbox"/>	QUADGUARD	<input type="checkbox"/>	HYDROCELL
	<input type="checkbox"/>	TRAC	<input type="checkbox"/>	
	<input type="checkbox"/>	REACT	SANDBARREL SYSTEM (pick)	
	<input type="checkbox"/>	TX BARREL CRASH CUSHION	<input type="checkbox"/>	FITCH
	<input type="checkbox"/>		<input type="checkbox"/>	ENERGITE
	<input type="checkbox"/>		<input type="checkbox"/>	TRAFFIX
<input type="checkbox"/>	OTHER:			

Foundation type:	<input type="checkbox"/>	CONCRETE	<input type="checkbox"/>	ASPHALT	<input type="checkbox"/>	DIRT
	<input type="checkbox"/>	OTHER:				

d) *TRANSITION*

<input type="checkbox"/>	GUARDRAIL-BRIDGE RAIL TRANSITION
--------------------------	----------------------------------

2. DID THE SYSTEM PERFORM AS INTENDED? (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.))

<input type="checkbox"/>	YES	<input type="checkbox"/>	NO
--------------------------	-----	--------------------------	----

Claim number:

PHASE I B:
SMALL AND LARGE SIGNS

1. CRASH INFORMATION (IF AVAILABLE)

1.1. Accident date:

MON	DAY	YR

1.2. Time of accident:

		:			(24 HOUR)
--	--	---	--	--	-----------

1.3. Accident location:

1.3.1

	Highway
--	---------

	Mile point
--	------------

1.3.2 Direction of Travel

	NORTH
--	-------

	EAST
--	------

	SOUTH
--	-------

	WE	
	ST	

1.3.3 Nearest intersection:

--

1.3.4 Distance to nearest intersection:

			miles
--	--	--	-------

1.4. Fatality:

	YES
--	-----

	NO
--	----

	UNK
--	-----

1.5. After the impact, did the vehicle:

	ROLLOVER
	STAY UPRIGHT

	UNK
--	-----

1.6. If there was rollover – was the rollover the result of impact with the safety feature?

	YES
--	-----

	NO
--	----

	UNK
--	-----

2. SELECT THE TYPE OF DEVICE:

a) *SMALL SIGN*

Support type:

<input type="checkbox"/> FIBER-GLASS	<input type="checkbox"/> STEEL PIPE: SCHEDULE 10
<input type="checkbox"/> U-CHANNEL	<input type="checkbox"/> STEEL PIPE: SCHEDULE 80
<input type="checkbox"/> STRUCTURAL SHAPES	
<input type="checkbox"/> OTHER:	

Base type:

<input type="checkbox"/> TRIANGULAR SLIP	<input type="checkbox"/> RECTANGULAR SLIP
<input type="checkbox"/> SOCKET SYSTEM	

Claim number:

b) LARGE SIGN

Number of supports:

Number of impacted supports:

Support type:	<input type="checkbox"/>	FIBER-GLASS	<input type="checkbox"/>	STEEL PIPE: SCHEDULE 10
	<input type="checkbox"/>	U-CHANNEL	<input type="checkbox"/>	STEEL PIPE: SCHEDULE 80
	<input type="checkbox"/>	STRUCTURAL SHAPES		
	<input type="checkbox"/>	OTHER:		

Base type:	<input type="checkbox"/>	TRIANGULAR SLIP	<input type="checkbox"/>	RECTANGULAR SLIP
	<input type="checkbox"/>	SOCKET SYSTEM		

3. DETAIL OF SYSTEM AND DAMAGE

1. Number of supports:

2. Number of impacted supports:

3. Support type:	<input type="checkbox"/>	FIBER-GLASS	<input type="checkbox"/>	STEEL PIPE: SCHEDULE 10
	<input type="checkbox"/>	U-CHANNEL	<input type="checkbox"/>	STEEL PIPE: SCHEDULE 80
	<input type="checkbox"/>	STRUCTURAL SHAPES		
	<input type="checkbox"/>	OTHER:		

4. Base type:	<input type="checkbox"/>	TRIANGULAR SLIP	<input type="checkbox"/>	RECTANGULAR SLIP
	<input type="checkbox"/>	SOCKET SYSTEM		

5. What is the stub height? inches

5. Did it breakaway as intended? YES NO

6. If it breakaway: did the support bend? YES NO

7. Did the slip-base slip activate? YES NO

8. If it did not breakaway: did any of the following occur?

<input type="checkbox"/>	THE SUPPORT RUPTURED
<input type="checkbox"/>	THE SUPPORT PULLED OUT OF THE SOCKET
<input type="checkbox"/>	THE FUSE PLATE RUPTURED

**APPENDIX C:
ISPE SITE INSPECTION FORMS FOR PHASE II**

Claim number:

PHASE II

MAINTENANCE INSPECTION DATA FORM FOR IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY FEATURES (TX 0-4366)

GENERAL INFORMATION

1. Accident date:

MON	DAY	YR

2. Time of accident:

		:			(24 HOUR)
--	--	---	--	--	-----------

3. Accident location:

3.1

	Highway
--	---------

	Mile point
--	------------

3.2 Direction of Travel

	NORTH		EAST		SOUTH		WEST
--	-------	--	------	--	-------	--	------

3.3 Nearest intersection:

--

3.4 Distance to nearest intersection:

--	--

 miles

4. Fatality:

	YES		NO		UNK
--	-----	--	----	--	-----

5. After the impact, did the vehicle:

	ROLLOVER		UNK
	STAY UPRIGHT		

6. If there was rollover – was the rollover the result of impact with the safety feature?

	YES		NO		UNK
--	-----	--	----	--	-----

Claim number:

GUARDRAIL SYSTEMS

1. Post type:

<input type="checkbox"/>	ROUND WOODEN
<input type="checkbox"/>	RECTANGULAR WOOD

<input type="checkbox"/>	STEEL POST
--------------------------	------------

2. Describe the post condition:

<input type="checkbox"/> DETERIORATION: YES – INDICATE %	<input type="checkbox"/> 0 – 25%	<input type="checkbox"/> 26 – 50%
	<input type="checkbox"/> 51 – 75%	<input type="checkbox"/> 76 – 100%

DETERIORATION: NO

Describe the deterioration (rotten, broken, missing elements etc.):

3. Blockout type:

<input type="checkbox"/>	NONE
<input type="checkbox"/>	WOOD

<input type="checkbox"/>	STEEL
<input type="checkbox"/>	PLASTIC

<input type="checkbox"/>	OTHER:
--------------------------	--------

4. Length of installation (including terminals)

--	--	--

 . nearest ft

5. Installation layout:

<input type="checkbox"/>	CURVE: inside
<input type="checkbox"/>	CURVE: outside

<input type="checkbox"/>	STRAIGHT
--------------------------	----------

6. Lateral offset from edge of pavement (ft):

--	--

 ft
Paved shoulder width (ft)

--	--

 ft

7. Describe the roadside:

<input type="checkbox"/>	FLAT ---
--------------------------	----------

<input type="checkbox"/>	DOWN SLOPE \
<input type="checkbox"/>	UP SLOPE /

8. Height to top of rail:

--	--

 inches (measured from adjacent top of asphalt unless more than a feet away, then from adjacent ground level)

9. Is a mowstrip present?

<input type="checkbox"/> YES: indicate type	Types:	<input type="checkbox"/> RIPRAP
<input type="checkbox"/> NO		<input type="checkbox"/> ASPHALT
<input type="checkbox"/> UNKNOWN		<input type="checkbox"/> CONCRETE
		<input type="checkbox"/> CONCRETE WITH LEAVE-OUT: LEAVE OUT MATERIAL?

10. Estimate the depth of the permanent deflection?

--	--	--

 ft

11.1 Was the rail (check all that apply):

<input type="checkbox"/>	FLATTENED
<input type="checkbox"/>	PARTIAL TEAR IN RAIL
<input type="checkbox"/>	RUPTURED

11.2 Length of damaged rail section:

--	--	--

 ft (length to be replaced)

12.1 Number of damaged posts:

--	--

12.2 What was the damage to the posts? (tick all appropriate)

<input type="checkbox"/>	DEFLECTED IN SOIL
<input type="checkbox"/>	BENT
<input type="checkbox"/>	FRACTURED

13. Was the impact in the transition area? (within 25ft of bridge rail, reduced post spacing)

<input type="checkbox"/>	YES
<input type="checkbox"/>	UNK

<input type="checkbox"/>	NO
--------------------------	----

14. DID THE SYSTEM PERFORM AS INTENDED? (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)

<input type="checkbox"/>	YES
--------------------------	-----

<input type="checkbox"/>	NO
--------------------------	----

15. COMMENTS & SKETCH (complete on back of form)

Claim number:

END TREATMENTS/ TERMINALS (SGT, GET)

1. Type of device:
- | |
|---------------|
| ET 2000 (& +) |
| BEST |
| OTHER: _____ |
- | |
|-------------|
| SKT 350 |
| TURNED DOWN |
- 2.1. Were the foundation tubes exposed? YES NO
- 2.2. If the foundation tubes were exposed, what is the height? inches
3. Is a mowstrip present?
- | |
|--------------------|
| YES: indicate type |
| NO |
| UNKNOWN |
- Type:
- | |
|--|
| RIPRAP |
| ASPHALT |
| CONCRETE |
| CONCRETE WITH LEAVE-OUTS:
LEAVE-OUT MATERIAL? |
4. Height to top of rail? inches (measured from adjacent top of asphalt unless more than a feet away, then from adjacent ground level)
5. Number of damaged posts:
- 6.1 Where did the impact initially occur: give the closest post number:
- 6.2 Was it upstream or downstream?

7. THE SYSTEM PERFORM AS INTENDED? (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)

YES NO

8. COMMENTS & SKETCH (complete on back of form)

IMPACT ATTENUATORS

1. Type of device:
- | |
|-------------------------------|
| GREAT |
| QUADGUARD |
| TRAC |
| REACT |
| TX BARREL
CRASH
CUSHION |
- | |
|--------------------------|
| HEXFOAM |
| HYDROCELL |
| SANDBARREL SYSTEM (pick) |
| FITCH |
| ENERGITE |
| TRAFFIX |
2. Foundation type: CONCRETE ASPHALT DIRT
3. Residual/ Undeformed length of installation (what is left): ft
4. Is the device properly shielding the obstacle? YES NO
5. Did all the components of the crash cushion (except for sand barrel systems) remain attached?
- YES NO
6. THE SYSTEM PERFORM AS INTENDED? (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)
- YES NO

**APPENDIX D:
PRELIMINARY FINDINGS REGARDING SGT PERFORMANCE
DURING PILOT TEST FOR TX 0-4366**

D1. INTRODUCTION

During the pilot test of the TxDOT-ISPE methodology, the research team received several enquiries regarding SGT devices and some of the ISPE case study files for these devices seem to indicate, although sufficient sample sizes were not obtained, that further investigation of these devices are warranted. [Appendix D](#) discusses the issues related to SGT devices and includes the recommendations from the research team regarding items that should be further investigated.

D2. BACKGROUND

The ET-2000, which was originally developed and tested under NCHRP Report 230 in 1989, was the first in the new generation of energy absorbing guard fence terminals. Texas was one of the first states in the U.S. to adopt and implement this revolutionary technology. The Beam Eating Steel Terminal (BEST), which was also initially developed under NCHRP Report 230 guidelines, was adopted by TxDOT upon its approval by FHWA in November 1994. In August 1995, the ET-2000 was approved by FHWA without change under NCHRP Report 350. A modified BEST-350 was later approved under NCHRP Report 350 in November 1996. The Sequential Kinking Terminal (SKT) was developed and approved under NCHRP Report 350 in April 1997. In July 2001, TxDOT removed the BEST-350 from their standards and adopted the SKT-350 in its place. As a result, the SGT inventory in Texas consists of three basic designs: the ET-2000, BEST, and SKT.

While these terminals have many similar characteristics, they also have some design differences that can lead to performance differences in the field. The ET-2000 and SKT both dissipate the energy of an impacting vehicle by first flattening the W-beam cross-section and then bending and deflecting it out of the path of the vehicle as shown in [Figure D1](#).



Figure D1: A Photograph Taken During the Pilot Test of an ET-2000 SGT That Performed As Intended.

The BEST incorporates a series of three “cutters” inside the head that cut or shear the W-beam cross-section into four smaller strips. These strips are then bent and deflected out of the head and away from the impacting vehicle as shown in [Figure D2](#).



Figure D2: An Example of the Activation of the BEST SGT Device.

Anecdotal observations derived from field crashes indicate that the BEST may be more likely to result in bending or buckling of the W-beam rail downstream from the impact head. It is theorized that the cutting behavior of the BEST is less consistent and reliable than the rail flattening that takes place in the ET-2000 and SKT. Field inspections indicate that the W-beam sometimes drifts inside the head, resulting in non-uniform strips. This behavior can increase the propensity for the rail to jam within the head, thus abruptly halting the cutting process and promoting buckling of the rail and gating of the head. To the extent possible with the data collected under this study, a comparative analysis of SGTs will be performed to determine if one design is more prone to a particular type of undesirable behavior than another. However, in order for this to be accomplished, the type of SGT will need to be identified and sufficient data for each type of terminal must be obtained.

It is important to note that several different configurations of each of these SGT systems exist in the field. These variations include the number of foundation tubes used in the installation (ranging from two to eight), the type of breakaway terminal posts used (including weakened round wood posts, rectangular wood posts, and hinged or welded steel posts), and changes to the impact head (e.g., the original ET-2000 versus the streamlined ET-PLUS).

During this process, maintenance sections raised several concerns regarding the performance of SGTs:

- effect of roadside geometry and improper grading,
- proper tensioning of the cable anchorage system,
- buckling of the rail at the entrance to the extruder head,
- failure of the cable to release during an end-on impact, and
- vehicle override.

Some of these issues are elaborated upon in more detail below.

D3. ROADSIDE GEOMETRY

Crash tests for the SGTs used by TxDOT were conducted in accordance with the requirements set forth in NCHRP Report 350 (I). As noted in NCHRP Report 350, the normalized testing conditions help provide a meaningful comparison between two or more systems, but “*may obscure serious safety deficiencies that exist under more typical but less ideal conditions.*” The test matrix for guard fence end treatments consists of up to eight tests. The installation for these tests typically consists of a straight, tangent section of guard fence installed on flat, level ground. In field installations, the guard fence is typically installed adjacent to a roadside slope that exists to provide parallel drainage along a highway. The standard installation details specify that the guard fence should be placed 2 ft from the edge of the slope break. If this 2-ft offset is not provided and the roadside terrain slopes from the edge of pavement, the height of the rail can be affected. If the rail is installed such that its height is in relation to the travelway, the height of the rail above the ground surface is effectively increased. This height can expose the foundation tubes that are used as part of the anchorage system of the end treatment that, in turn, creates a snag point that can result in excessive deceleration of the vehicle. Additionally, the increased rail height increases the propensity for a vehicle to underride the system when hitting the terminal end-on while attempting to return to the roadway. This concern is heightened for passenger cars that have a low front profile or aerodynamically sloped front end.

If the guard fence is installed on a roadside slope, as shown in [Figure D3](#), and the height is maintained relative to the ground rather than the travelway, the rail will be underheight with respect to the travelway. Impacting a terminal in such a situation can lead to the impacting vehicle becoming unstable and/or overriding the system. Some impact conditions may be more conducive to this problem than others. It is therefore important to understand the fundamental behavior of the terminal system and its components and how installation and site variations might affect impact performance. Members of the proposed team have developed such insight through their experience in designing, testing, and evaluating various guard fence terminals and participating in previous in-service evaluation efforts.



Figure D3: An Example of An ET-2000 Installed On a Slope.

D4. EFFECT OF FLARE

In order to maximize extrusion of the rail and, thus, energy dissipation of an impacting vehicle, it is desirable to install the SGTs in a straight or tangent layout along the edge of the road. However, this proximity to the travelway, combined with the additional encroachment of the impact head, tends to increase the frequency of impacts relative to systems that are flared away from the road as shown in [Figure D4](#). During the Phase I in-service pilot test, maintenance sections reported that the impact head of the SGT systems are frequently being hit on the inside edge by passing vehicles. In addition to the obvious maintenance problem this creates, these impacts often push the head of the SGT out of proper alignment, thus increasing the probability of undesirable impact performance during subsequent impacts that occur between the time of the initial impact and identification, reporting, and repair of the terminal.



Figure D4: An Example of a Flared ET-2000 Device.

In order to help alleviate this problem, an end offset of up to 2 ft is permissible using a 1:25 flare rate. However, when an energy-absorbing system is flared away from the road to reduce the crash frequency, the effective impact angles tend to increase, which decreases the amount of rail extrusion and increases the incidence of “gating” through and behind the terminal system. This gating behavior initiates as the rail buckles or bends downstream from the impact head due to the eccentric load applied by the angled hit of the vehicle. The impact head then “hinges” about the weakened section of rail and swings behind the terminal, thus permitting the vehicle to encroach onto the terrain behind the terminal. It is important to understand that gating does not necessarily constitute failure or improper performance of the system. In fact, all guard fence terminals function as gating systems, even if they are installed tangent to the guard fence without a flare. In most instances, the vehicle merely passes behind the terminal without undesirable consequences. However, there have been reports that in some crashes, the “elbow” formed in the rail at the hinge point has penetrated the occupant compartment of the vehicle.

This behavior was not observed in any of the impacts reported during the pilot test of the ISPE process.

Flaring the terminal away from the travelway also increases the impact angle for redirection impacts along the length of the terminal. For a vehicle leaving the road at a given angle, the effective impact angle with the terminal is increased by the angle at which the guardrail is flared. The increased effective impact angle places more demand on the rail and anchorage system, and increases the probability of exceeding the design capacity of the terminal system. For a 2 ft offset in 50 ft, the flare angle of the rail is 2.3 degrees.

Another aspect of flaring the SGTs away from the roadway is that the offset places the end of the terminal further out onto the roadside slope. This increases the cost associated with achieving the necessary grading requirements around the terminal. If proper grading is not achieved, the rail height issues previously described will be aggravating by the flare.

Thus, there is a relationship between the terminal flare rate, crash frequency, crash severity, and installation and maintenance costs. TxDOT may be interested in knowing how flaring SGTs affects the frequency or severity of terminal gating crashes in order to be able to assess the cost effectiveness of current terminal layout and installation practices. This can only be achieved through an ISPE process with sufficient sample sizes as discussed in [Chapter 5](#) of this report.

D5. TENSIONING OF SGT ANCHORAGE

There are currently no specifications regarding the tensioning of the cable in SGTs. The purpose of the cable anchorage system is to provide anchorage of the terminal for redirection impacts along its length. It is not uncommon to see slack cables on SGTs installed in the field. During training sessions conducted in conjunction with the Phase I pilot test of the in-service performance evaluation project, maintenance personnel expressed concern about the lack of requirements regarding tensioning during installation and whether follow-up maintenance is necessary if cables become slack after installation.

The cable anchor and cable anchor box are designed to release from the terminal in an end-on impact. Therefore, cable tension is not critical for end-on crashes. In redirection impacts, the cable plays a critical role in developing tension in the rail to permit successful containment of the impacting vehicle. The cable transmits these forces into the ground to

prevent the lead posts in the terminal from failing. Any slack in the cable must be taken out before any appreciable tension can be developed in the system to redirect a vehicle. Therefore, slack in the cable can translate into increased lateral deflection. While the effect of a slack cable on a terminal's redirection capacity is not fully known, similar cable anchorage systems have been successfully tested in terminals with a 4 ft end offset over a terminal length of 37.5 ft. Although the details vary somewhat between these flared and tangent systems, these tests indicate that the cable anchorage system has reserve capacity for terminals installed on a straight tangent or reduced flare (e.g., 2 ft in 50 ft).

D6. BUCKLING OF THE EXTRUDER HEAD

In end-on crashes that occur at an impact angle other than zero degrees, the extruder head will typically buckle and bend to the side during some stage of the impact as shown in [Figure D5](#). During training sessions for the in-service performance evaluation pilot test, the researchers found that maintenance personnel normally regard this behavior as a failure of the terminal. While this may be true in some instances, it must be recognized that the majority of time this behavior is falls within the expected design performance of the SGT when it is subjected to an end-on impact at an angle with respect to the length of the terminal.

As mentioned in Section D4 all SGTs function as gating systems, even if they are installed without a flare. When the vehicle hits the impact head at an angle, it introduces eccentricity between the rail and the line of action of the impact force. The moment induced on the end of the rail by this eccentricity causes the rail to buckle and bend. The impact head swings or hinges about the bend point in the rail, and the vehicle passes proceeds behind the terminal. A head-on, zero degree impact will also introduce eccentricity and may result in similar rail behavior if the point of vehicle contact with the impact head is offset from the center of the vehicle. The amount of rail extruded prior to bending or kinking the rail is a function of several variables including the angle of impact, vehicle mass, and impact speed. A higher impact angle introduces greater eccentricity and greater moment on the end of the rail, thus, less rail is extruded prior to bending the rail. As a result, less of the vehicle's kinetic energy is dissipated, and the vehicle gates through the system at higher speed. If the SGT is flared, the eccentricity can further increase, thus aggravating the bending/buckling behavior. There have been reports that in some of these crashes in which the rail bends and buckles upstream of the impact head,

the “elbow” formed in the rail at the hinge point has penetrated the occupant compartment of the vehicle. This behavior should be investigated further in a SGT specific ISPE project, i.e., where significant samples of ISPE information can be collected.



Figure D5: An Example of An Extruder Head Buckling: Note that, In This Case, The SGT Performed As Intended. The Buckling of the Extruder Head Do Not In Itself Imply That the Device Did Not Perform As Intended.

D7. FAILURE OF SYSTEM COMPONENTS

During the Phase I in-service pilot test, selected participating maintenance sections observed selected crashes in which an SGT failed to perform as designed due to component failures. In one such crash, as shown in [Figure D6](#), the first post of the terminal failed to release the cable anchor as designed. Although the first post fractured, the failure plane was above the weakening hole through which the cable passes. Since the cable did not release from the first post, tension developed in the cable when the impact head contacted the anchor box attached to the back side of the rail. As a result, the extrusion of the rail and the forward motion of the impacting vehicle were abruptly stopped.



Figure D6: An Example of an ET-2000 Impact Observed During the Pilot Test.

The failure of the wood post to fracture as designed was likely due to the presence of large defects (e.g., knots) in wood post just above weakening hole. The defect was sufficiently large that it weakened the post more than the drilled hole, and the post failed at the knot rather than through hole as intended. This prevented the cable from releasing from post 1 and feeding

of the rail stopped abruptly when the extruder head contacted the cable anchor box. This scenario is thought to be rare event and no injuries or fatalities were reported for the impact.

D8. CONCLUSIONS AND RECOMMENDATIONS

Although Project 0-4366 did not obtain sufficient sample sizes to present statistically valid conclusions, SGT devices were flagged as the device type that could warrant further investigation. This conclusion is made based on feedback provided during the pilot test process and based on reported ISPE cases. It is recommended that, unless a Phase I screening ISPE phase can be implemented to identify, based on sufficient sample sizes, which devices or device types should be subjected to a Phase II ISPE process, TxDOT conduct a Phase II ISPE study on SGT devices.

**APPENDIX E:
TRAINING MATERIALS FOR PHASE I –
MICROSOFT POWERPOINT SLIDES**




IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY FEATURES

TX 0-4366 (RMC3)


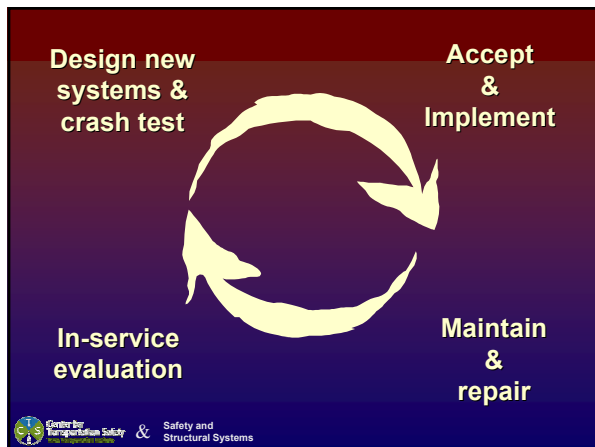

Presented by:
Dean Alberson & Ida van Schalkwyk






OVERVIEW

- The research project
- Topics
 - Systems
 - How they work
 - How they fail
 - Guardrails, end-terminals, signage, impact attenuation devices, transitions



THE RESEARCH PROJECT

- Purpose
 - Develop process to evaluate in-service performance of roadside safety features in TX
 - Performance in the field
 - Detect problems
 - Failures
 - Applications
 - Design load exceeded
- Method
 - Phase I
 - Phase II


THE RESEARCH PROJECT *(cont)*

- Phase I
 - Basic questions
 - Signage
 - Other: Guardrails, transitions, impact attenuation devices, end treatments
 - Type of system?
 - Did it perform as intended?
 - Pilot will test basic questions
- Phase II
 - Detailed research study
 - Another pilot to test Phase II questions

THE SYSTEMS

- Guardrails
- Transitions
- Impact attenuation devices
- End treatments
- Signs
 - Small signs
 - Large signs



GUARDRAIL SYSTEMS

OVERVIEW

- The form
- The issues
- Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form

THE FORM

- Post type
- Post condition
- Blockout type
- Length of installation
- Installation layout
- Lateral offset
- Describe the roadside
- Height to top of rail
- Mowstrip?
- Depth of permanent deflection
- Rail condition after impact
- Length of damaged rail
- Number of damaged posts
- Damage to posts
- Impact in the transition area?

1. Post type

- Round wooden
- Rectangular wood
- Steel post




2. Post condition: Deterioration?

↓	↓	↓	↓
0% - 25%	26% - 50%	51% - 75%	76% - 100%

3. Blockout type

- None/ wood/ steel/ plastic




4. Length of installation

Center for Transportation Safety & Structural Systems

5. Installation layout

> On curve

Outside of curve

Inside of curve

> On straight

Center for Transportation Safety & Structural Systems

6. Lateral offset

shoulder

Lateral offset from edge of pavement

Edge of traveled lane

Edge of pavement

Center for Transportation Safety & Structural Systems

7. Height to top of rail

Height to top of rail

Center for Transportation Safety & Structural Systems

8. Mowstrip?

Center for Transportation Safety & Structural Systems


9. Depth of permanent deflection?

Center for Transportation Safety & Structural Systems


TRAINING MATERIAL: SLIDES PHASE I

10. Rail condition after impact


Flattened



Partial tear in rail



Ruptured:
Tear all through



 Center for Transportation Safety & Safety and Structural Systems

11. Length of damaged rail

11.1 Number of damaged posts

11.2 Damage to posts


- Deflected in soil
- Bent (steel)
- Fractured (wood)



 Center for Transportation Safety & Safety and Structural Systems

12. Impact in the transition area?

Within 25 ft of bridge rail


TRANSITION = within 25 ft




 Center for Transportation Safety & Safety and Structural Systems

OTHER INFO

- Did it perform as intended?**
 - Remember comment & sketch!
- Photographs**
 - Critical
- Maintenance cost & labor**
- Accident report form**
 - If available
 - Valuable info for Phase II


 Center for Transportation Safety & Safety and Structural Systems

TRANSITIONS


Guardrail to Bridge Rail




 Center for Transportation Safety & Safety and Structural Systems


1. **SELECT THE TYPE OF DEVICE:**
 - d) **TRANSITION**
 - W-BEAM GUARDRAIL TRANSITION
 - THREE BEAM TRANSITION
2. **DID THE SYSTEM PERFORM AS INTENDED?** (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.))

YES
 NO


 Center for Transportation Safety & Safety and Structural Systems


TRANSITIONS

- How is transition different from guardrail section?
- Types
 - W-beam transitions
 - Thrie beam transitions




W-BEAM TRANSITIONS

- Transition to
 - Flexible W-beam guardrail TO
 - Rigid / semi-rigid bridge rails
- How they work
 - Gradual stiffening through addition of posts in 25' adjacent to bridge rail
- To T501
 - W-beam, shoe & through bolts
- To T4
 - Embedded steel angle extending from end of concrete portion of bridge rail – Placed in front of the W-beam @ approx front of bridge rail




THRIE BEAM TRANSITIONS

- How they work
 - Transition
 - Flexible W-beam / thrie beam guardrail TO
 - Rigid/ semi-rigid bridge rail
- Multiple transition sections
- Incremental stiffening of rail
 - Increased beam size
 - Beam nesting
 - Post spacing
 - Post embedment depth
- Nominal 6" curb used with nested thrie beam section




TRANSITIONS (cont)

- When they don't perform as intended
 - Excessive deflections near end of bridge rail
 - Cause snagging
 - Posts & rail displaced
 - Rigid end section of bridge rail exposed
 - Wheel and rim of vehicle
 - Vehicle instabilities
 - Potential: large occupant compartment deformations





TRANSITIONS

Questions?



Safety and Structural Systems

IMPACT ATTENUATORS



Safety and Structural Systems

1. **SELECT THE TYPE OF DEVICE:**

c) **IMPACT ATTENUATORS**

Type of device:

<input type="checkbox"/> QUADGUARD Wide	<input type="checkbox"/> SANDBARREL SYSTEM (pick)
<input type="checkbox"/> QUADGUARD Elite	<input type="checkbox"/> FITCH
<input type="checkbox"/> REACT Narrow	<input type="checkbox"/> ENERGITE
<input type="checkbox"/> REACT Wide	<input type="checkbox"/> TRAFFIX
<input type="checkbox"/> GREAT	
<input type="checkbox"/> TX BARREL CRASH CUSHION	
<input type="checkbox"/> TRAC	
<input type="checkbox"/> HEXFOAM	
<input type="checkbox"/> HYDROCELL	
OTHER: _____	


Foundation type: CONCRETE ASPHALT DIRT

OTHER: _____

Width of object protected: _____

2. **DID THE SYSTEM PERFORM AS INTENDED?** (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)

YES NO



Safety and Structural Systems



IMPACT ATTENUATORS

How they work

- Increases the time it takes for the vehicle to slow down (“parachute”)

When they don’t perform as intended

- When the vehicle made contact with the object it protected
- When the vehicle rolled over

Safety and Structural Systems

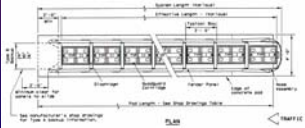

QUADGUARD

Redirective (non-gating)

- Shields roadside & median hazards

Impacted on nose

- System collapses
- Crush foam cartridges to consume energy from vehicle
- Amount of collapse
 - Vehicle type
 - Impact speed
 - Impact angle





Safety and Structural Systems

QUADGUARD

Impacted on side

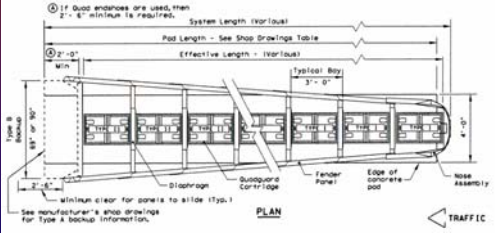
- Vehicle redirected & shielded from hazard
 - Fender panels
 - Diaphragms
 - Monorail system




Safety and Structural Systems

QUADGUARD Wide

- Protect 8-ft wide hazards



The technical drawing shows a side view of the QUADGUARD Wide system. It features a series of vertical posts connected by a top rail. Key dimensions include a system length of 10'-0" and an effective length of 8'-0". Components labeled include a diaphragm, substructure carriage, fender panel, edge of concrete post, and nose assembly. A note indicates that if dual endposts are used, a 2'-0" minimum is required. A 'PLAN' view shows the system's width and the direction of traffic flow.




QUADGUARD Elite






QUADGUARD Elite (cont)

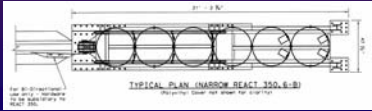
- How the system functions
 - Use re-usable high density polyethylene cylinders as energy absorbing medium
 - Impacted on nose
 - System collapses & crushes HDPE cylinders (consume energy)
 - After impact:
 - HDPE largely self-restore to original shape
 - Impacted on side
 - Redirection






REACT Narrow

- Non-gating
- Use HDPE vertically oriented cylinders
- Steel cables on each side
 - Re-directive type impacts
 - Steel undercarriage
 - Anchorage
 - Cylinders & cables
 - To the road surface

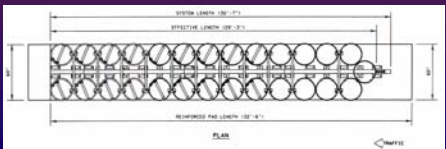


The technical drawing shows a side view of the REACT Narrow system, highlighting the arrangement of HDPE cylinders and steel cables. It includes a 'TYPICAL PLAN (NARROW REACT 350, 6-8)' and shows the system's width and the direction of traffic flow.




REACT Wide

- Non-gating
- Use HDPE vertically oriented cylinders
- Parallel rows of HDPE cylinders mounted atop monorail system to protect wide objects

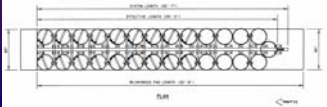


The technical drawing shows a side view of the REACT Wide system, illustrating the parallel rows of HDPE cylinders mounted on a monorail. It includes dimensions for system length, effective length, and monorail length.




REACT Wide (cont)

- Steel diaphragms
 - Transmit load to base track/monorail in redirective impact
- Steel undercarriage
 - Anchorage to cylinders
 - Anchorage to road surface

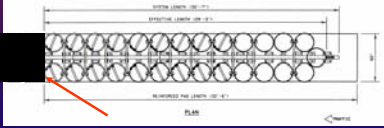



The technical drawing shows a side view of the REACT Wide system, focusing on the steel undercarriage and its anchorage to the cylinders and road surface. It includes dimensions for system length, effective length, and monorail length.



REACT Wide (cont)

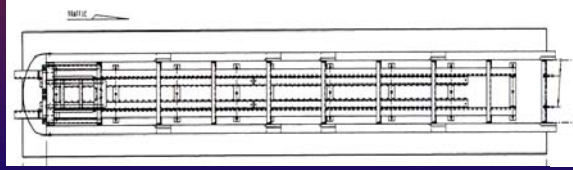
- FAILURE
 - Excessive deflections near rear of system – Vehicle contact object shielded by the system





 Center for Transportation Safety & Safety and Structural Systems

TRACC System



- Redirective, non-gating





 Center for Transportation Safety & Safety and Structural Systems

TRACC System (cont)


- Impacted on the NOSE
 - System collapses
 - Tears perforated plates within system undercarriage (consume energy)
 - Amount of collapse
 - Vehicle type
 - Impact speed
 - Impact angle






 Center for Transportation Safety & Safety and Structural Systems

TRACC System (cont)

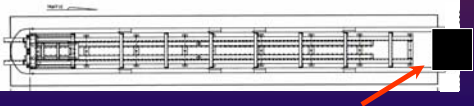
- Impacted on SIDE
 - Redirection from shielded object
 - Fender panels
 - Diaphragms
 - Undercarriage





 Center for Transportation Safety & Safety and Structural Systems

TRACC System (cont)


- When TRACC doesn't perform as intended
 - Excessive deflections near rear of system
 - Vehicle made contact with the object it protected





 Center for Transportation Safety & Safety and Structural Systems

SAND BARREL SYSTEM

- Non-redirective
- Conservation of momentum
 - Reduction of vehicle velocity when sand accelerated to velocity close to vehicle velocity
- Staging of sand
 - Staged in increased manner
 - Prevent excessive decelerations to impacting vehicle
 - And still reduces vehicle speed before it reaches the shielded object




 Center for Transportation Safety & Safety and Structural Systems


SAND BARREL SYSTEM (cont)

□ FAILURE

- Excessive deflections near rear of system
 - Vehicle made contact with the object it protected
- Moisture collected in sand
 - Degrade impact performance
- Incorrect installation
 - Premature stoppage of vehicles & excessive damage




Impacted system: Performed as intended





TX BARREL SYSTEM

□ Non-redirective



- Gore areas & medians

□ 55 gallon drums

- Varied crush strength
 - Top & bottom lid section modification

□ IMPACTED


- Barrels crushed
- Impact other than nose
 - System crushes
 - Vehicle captured

TX BARREL SYSTEM (cont)

□ FAILURE

- Excessive deflections near rear of system
 - Vehicle made contact with the object it protected
- Not tested to current standards (NCHRP 350)
 - ? Pickups & SUV's
 - *Field experience only*




Impact on nose Impact on other than nose





Center for Transportation Safety & Safety and Structural Systems

IMPACT ATTENUATORS

□ Questions?

Center for Transportation Safety & Safety and Structural Systems

END TREATMENTS

Center for Transportation Safety & Safety and Structural Systems

1. **SELECT THE TYPE OF DEVICE:**

b) **END TREATMENTS/ TERMINALS**

Type of device: ET 2000 (& +) SKT 350
 BEST TURNED DOWN
 OTHER:

2. **DID THE SYSTEM PERFORM AS INTENDED?** (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded, etc.)

YES NO

Center for Transportation Safety & Safety and Structural Systems

SINGLE GUARDRAIL TERMINALS

- Tube height
 - > <4"
 - Snagging vehicle undercarriage
- Graded terrain
 - > Vehicle pass over non-breakaway portion of installation
- Cross-slope of surrounding terrain (10:1 preferred)
 - > Steeper may cause >4" tube

Center for Transportation Safety & Safety and Structural Systems

SINGLE GUARDRAIL TERMINALS

- Installed wrong
- Too much foundation tube showing
- Ground strut should be on ground


Center for Transportation Safety & Safety and Structural Systems

SINGLE GUARDRAIL TERMINALS



Terminal head should be aligned with the guardrail system

Center for Transportation Safety & Safety and Structural Systems



Loose cable

Center for Transportation Safety & Safety and Structural Systems

END TREATMENTS

- Normally gating & redirective
- Failures
 - Impacts on end
 - Improper feeding of W-beam through impact head
 - Improper "gating"
 - More problematic: Smaller vehicles
 - Improper activation
 - May cause excessive rotation on the vehicle
 - Present side of occupant compartment
 - Guardrail deformation of the occupant compartment
 - Redirective impacts
 - Rail rupture
 - Loss of anchorage
 - And/or excessive pocketing

Center for Transportation Safety & Safety and Structural Systems

END TREATMENTS (cont)

- Failures (cont)
 - Redirective impacts (cont)
 - Rail rupture
 - Vehicles allowed into areas where guardrail shielded
 - May cause spearing on unprotected & ruptured ends
 - Loss of anchorage
 - When: Premature release of the anchor cable on
 - Either end
 - W-beam or
 - Post 1
 - Vehicles allowed into areas where guardrail shielded
 - May cause spearing on unprotected & ruptured ends
 - Can cause rail element to drop
 - Cause ramping

Center for Transportation Safety & Safety and Structural Systems

END TREATMENTS (cont)

- Failures (cont)
 - Redirective impacts (cont)
 - And/or excessive pocketing
 - When
 - Partial loss of anchorage +/-
 - Excessive post deflections
 - Breakage
 - Cause
 - Excessive roll
 - Pitch angles
 - May result in rail rupture

Center for Transportation Safety & Safety and Structural Systems

BEST




http://www.mdot.state.mn.us/design/nd_terminal/images/best1.jpg

www.und.edu/match/best.jpg

Center for Transportation Safety & Safety and Structural Systems

BEST (cont)

- HIT "END-ON" (@ 0 degrees)
 - W-beam feeds through impactor head
 - Cuts W-beam in 4 plate sections
 - Deflects away from vehicle
- HIT @ larger angles near nose of device
 - End of system "gates"
 - Allows vehicle to pass through the end section
- Breakaway posts in terminal & fracture/release when impacted in weak axis





BEST (cont)


- Vehicle redirection
 - IF System impacted
 - @ post 2
 - < 25 degree impact angle
 - < 60 mph
 - Vehicle <= ¾ pickup



ET 2000 (&+)

- Impact "end-on"
 - @ 0 degrees
 - Flattens & deflects w-beam guardrail
 - @ greater angles near nose
 - End of system "gates"
 - Vehicle pass through the end section
 - Impact on post 2 or beyond
 - Redirection if
 - <= ¾ pickup
 - < 25 degrees
 - < 60 mph






ET 2000 (&+) (cont)

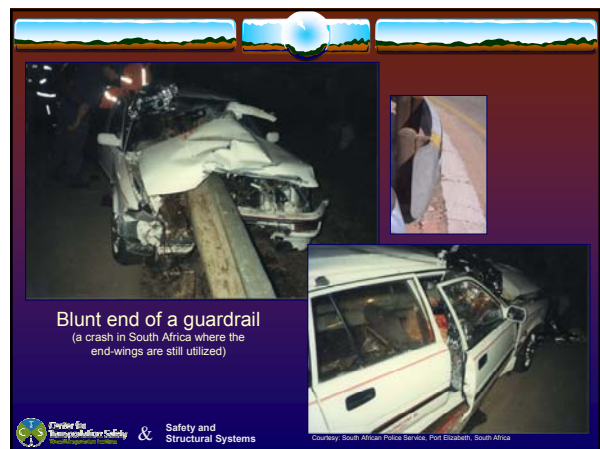
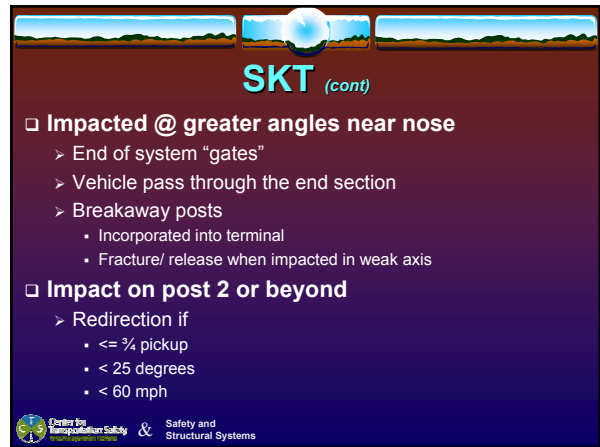
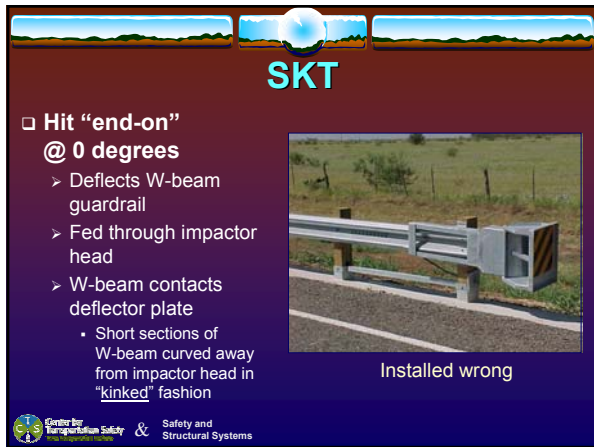





ET 2000 (&+) (cont)

- Example:
 - High angle impact
 - Terminal gated
 - Note wheeltracks
 - Little fed through, but still OK




TRAINING MATERIAL: SLIDES PHASE I

TURNED DOWN TERMINAL (cont)


- 25' guardrail section, twisted down to ground level & attached to concrete block for anchorage
 - > Anchorage provides tension to guardrail system
- Use
 - > Downstream ends of one-way facilities
 - > When OUTSIDE clear zone: 2 way facilities
- Why other systems?
 - > Experience: vehicle ramping &/rollover

Center for Transportation Safety & Safety and Structural Systems

TURNED DOWN TERMINAL (cont)



Hit in length of need
(redirection only)



Vehicle got on system

Center for Transportation Safety & Safety and Structural Systems

END TREATMENTS

- Questions?

Center for Transportation Safety & Safety and Structural Systems

SIGNS



Center for Transportation Safety & Safety and Structural Systems

2. SELECT THE TYPE OF DEVICE:

Sign size: < 16 ft² 16 ft² > 16 ft²

Number of supports:

Number of impacted supports:

Support type: FIBER-GLASS STEEL PIPE: SCHEDULE 10
 U-CHANNEL STEEL PIPE: SCHEDULE 80
 STRUCTURAL SHAPES

OTHER:

Base type: TRIANGULAR SLIP RECTANGULAR SLIP
 SOCKET SYSTEM

Center for Transportation Safety & Safety and Structural Systems

3. DETAIL OF SYSTEM AND DAMAGE

1. Post type: U-CHANNEL STEEL PIPE: SCHEDULE 10
 I-BEAM STEEL PIPE: SCHEDULE 80
 FIBER-GLASS STRUCTURAL SHAPES
 OTHER:

2. Base type: TRIANGULAR SLIP RECTANGULAR SLIP
 SOCKET SYSTEM

3. What is the stub height? inches

4. Did it break away as intended? YES NO

5. If it did break away: did the support bend? YES NO

6. Did the slip-base slip activate? YES NO

7. If it did not break away: did any of the following occur?
 THE SUPPORT RUPTURED
 THE SUPPORT PULLED OUT OF THE SOCKET
 THE FUSE PLATE RUPTURED

Center for Transportation Safety & Safety and Structural Systems

SMALL SIGNS

Center for Transportation Safety & Safety and Structural Systems

SMALL SIGNS

- How they work
 - Breakaway
 - Uncoupling – Slip plane
 - Yielding – Permit failure of support material/ material connected with
- Uni or multi-directional
- Sign installation yield
 - >= 35 mph
 - Impact angle:
 - Uni-directional: 0 – 20 degrees
 - Multi-directional: Not sensitive to impact angle

Still a small sign!

Center for Transportation Safety & Safety and Structural Systems

SMALL SIGNS (cont)

- Critical issues
 - >= 4" stub height
 - Breakaway supports in multiple support sign structures
 - Rigidity for multi-post supports to activate breakaway device
 - Orientation: Ensure acceptable dynamic performance

Center for Transportation Safety & Safety and Structural Systems

SMALL SIGNS (cont)

- Types
 - Universal anchor system – Type A (fiber-glass)/ thin tube
 - TX universal triangular slip base
 - Perforated square metal tubing (drivable) – Type U
 - Wedge anchor thin wall (drivable) – Type A

Center for Transportation Safety & Safety and Structural Systems

Universal Anchor System
– Type A (fiber-glass) / thin tube (cont)

- When hit
 - Yield to vehicle
 - Either pulling out of ground anchor tube
 - Fracturing tube support near top of ground OR
 - Collapsing tube cross section
 - Displaced from soil

Center for Transportation Safety & Safety and Structural Systems

Universal Anchor System
– Type A (fiber-glass) / thin tube (cont)

- Improper impact performance
 - Sign support failing to yield
 - Yield in such a manner: Support/ sign panel penetrate into occupant compartment from any surface of the vehicle
 - Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil

Center for Transportation Safety & Safety and Structural Systems

TRAINING MATERIAL: SLIDES PHASE I



TX Universal Triangular Slip Base

- 3 bolts clamp individual slip base components together

TX Universal Triangular Slip Base (cont)

- When hit
 - Bolts forced out of slots in base
 - Support(s) yield to vehicle
 - By allowing top support to release from stub post by
 - Pushing out 3 bolts clamping upper & lower section together
 - Thus: releasing slip base
 - Schedule 10: Field experience
 - May bend over rather than release from slip base
 - Not a hazard to motorist
 - BUT need to be noted during inspection

TX Universal Triangular Slip Base (cont)

- Improper impact performance
 - Sign support failing to yield
 - Sign support yielding in such a manner
 - Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
 - Slip base support not separate from slip base stub post – "locked up" = FAILURE
 - Proper hardware during installation?
 - Assembly torque during installation?
 - Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil



TRAINING MATERIAL: SLIDES PHASE I



Perforated Square Metal Tubing (drivable) – Type U

- Proprietary corner bolt & flanged washer nut secure support to ground anchor stub
- When hit
 - Support(s) yield to vehicle
 - Top support release from ground stub by
 - Fracturing cross-section of support @ or near top of ground & laying over

Center for Transportation Safety & Safety and Structural Systems

Perforated Square Metal Tubing (drivable) – Type U (cont)

- Improper impact performance
 - Sign support failing to yield
 - Sign yielding in such a manner
 - Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
 - Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil

Center for Transportation Safety & Safety and Structural Systems

U-channel

- Lap-splice connection
- Fractured @ bumper height
- Base activated
- "Marginal" performance

Center for Transportation Safety & Safety and Structural Systems

U-channel
Back to back = Undesirable
Directly buried = Not TXDOT practice

Center for Transportation Safety & Safety and Structural Systems

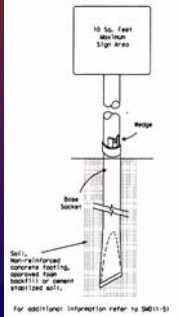
U-channel lap splice - INCORRECTLY installed

Center for Transportation Safety & Safety and Structural Systems



Wedge Anchor Thin Wall

(drivable) – Type A

- ❑ Sign max 10 ft²
- ❑ When hit
 - Yield to vehicle by
 - Allow top support to release from ground stub by
 - Pulling out of ground anchor tube
 - Collapsing tube cross section
- ❑ Improper impact performance




For additional information refer to S&S-03

Wedge Anchor Thin Wall

(drivable) – Type A (cont)

- ❑ Improper impact performance
 - Sign support failing to yield
 - Sign support yielding in such a manner
 - Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
 - Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil






! Why isn't this sign post falling over?







TxDOT did away with all buried supports






Post pulled from ground stub – GOOD performance




Stub height





TRAINING MATERIAL: SLIDES PHASE I



Is this welded?
"... plumbing"

Is the wedge type
full of water or
debris?

 Center for Transportation Safety & Safety and Structural Systems




Stub too high

Socket system – Did not activate
will fall over

 Center for Transportation Safety & Safety and Structural Systems

SMALL SIGNS

□ Questions?

 Center for Transportation Safety & Safety and Structural Systems




LARGE SIGNS

 Center for Transportation Safety & Safety and Structural Systems

LARGE SIGNS

□ How they work


- > Give way to errant vehicle impacting the system
 - Uncoupling: through slip plane (slip base) near ground level
 - Permitting material failure of perforated hinge fuse plate
 - Connecting: Upper and lower supports together
 - Due to mass of large support size
 - Support member hinge fuse plate mechanism near base of sign panel is necessary
- > When impacted at
 - ≥ 35 mph &
 - Impact angle: 0-25 degrees

 Center for Transportation Safety & Safety and Structural Systems

LARGE SIGNS

□ Critical elements

- > Substantial remains of breakaway supports $< 4"$
- > Multipost breakaway sign supports
 - Hinge: $> 84"$ above ground level
 - No portion of sign/ upper section of support likely to penetrate windshield of impacting car/ medium- sized truck
 - Single post spaced with clear distance $84"$ or more from another post
 - Mass ≤ 44 lb/ft
 - Total mass below hinge but above shear plate of breakaway base: ≤ 600 lb
 - No supplemental sign attached below hinges – If interfere with breakaway action of support post / penetrate windshield


 Center for Transportation Safety & Safety and Structural Systems

LARGE SIGNS

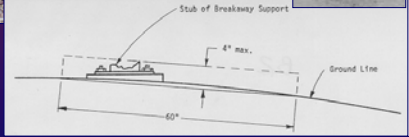
❑ **Critical elements (cont)**

- Multipost breakaway sign supports (cont)
 - Each support consider acting together UNLESS
 - Sign supports designed to independently release from sign panel +
 - Sign panel has sufficient torsional strength to ensure this release +
 - Clear distance between supports = >84"
 - Sufficient strength in connections between post & sign to allow hinge system to function on impact
- Slip base breakaway device: Oriented in direction that ensures acceptable dynamic performance

& Safety and Structural Systems



Stub height



& Safety and Structural Systems

3-BOLT SLIP BASE

❑ **How they work**

- Bolts forced out of slots in the base
- Perforated hinge fuse plate fails on impacted side of support
- Bends/ fractures at opposite flange
- Permits the support to separate from the sign panel
- Normally: Sign installation remains upright & intact
 - Only bolts, keeper plate & fuse plate needs replacement

❑ **When they don't perform as intended**

& Safety and Structural Systems

3-BOLT SLIP BASE (cont)

❑ **When they don't perform as intended**

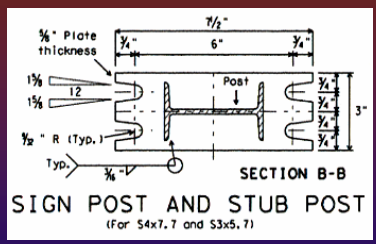
- Sign support failing to yield
- Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
- Slip base support don't separate from slip base stub post = locked up
 - Proper hardware?
 - Assembly torque during installation?
 - Fuse plate: if not activate – Compare with TXDOT std drawings
- Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil

& Safety and Structural Systems



Post on left buried – Will not perform as intended!

& Safety and Structural Systems



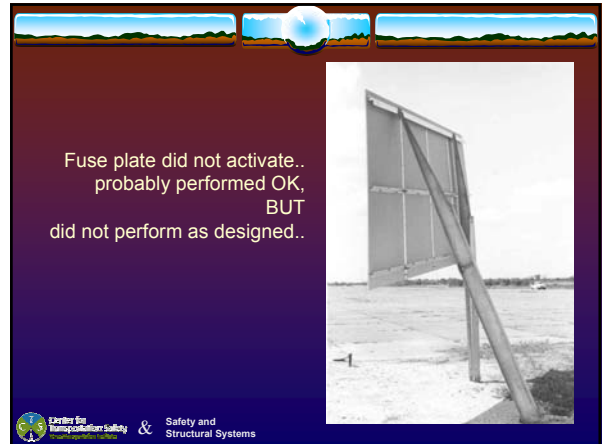
SECTION B-B
SIGN POST AND STUB POST
(For S4x7.7 and S3x5.7)

& Safety and Structural Systems

TRAINING MATERIAL: SLIDES PHASE I

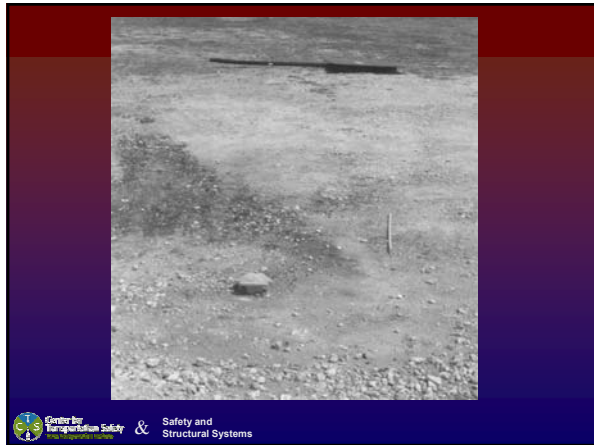


Center for Transportation Safety & Safety and Structural Systems



Fuse plate did not activate.. probably performed OK, BUT did not perform as designed..

Center for Transportation Safety & Safety and Structural Systems



Center for Transportation Safety & Safety and Structural Systems



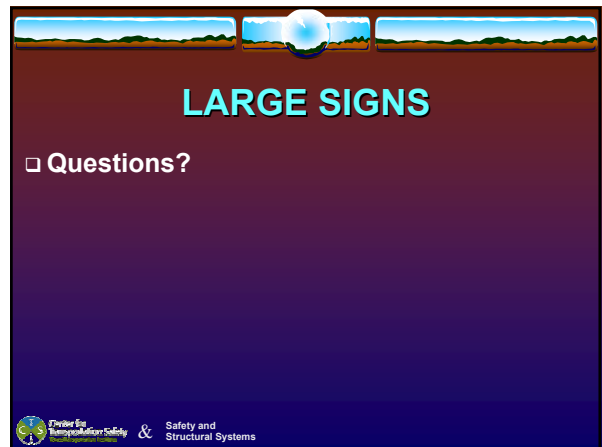
Round support with wide flange support – Behind guardrail

Center for Transportation Safety & Safety and Structural Systems



Ground stub too high


Center for Transportation Safety & Safety and Structural Systems



LARGE SIGNS


□ Questions?

Center for Transportation Safety & Safety and Structural Systems





CONCLUSION

- Different systems in use by TxDOT
 - In-service performance evaluation = Needed
- We looked at the different systems and discussed how we would complete the questions
 - Guardrails
 - Transitions
 - Impact attenuation devices
 - End-treatments
 - Signs: Small & Large



Safety and Structural Systems

QUESTIONS



Safety and Structural Systems



THE END



Safety and Structural Systems

**APPENDIX F:
TRAINING MATERIALS FOR PHASE I – MANUAL**

1. GUARDRAIL SYSTEMS

How the system functions:

A guardrail system redirects errant vehicles that inadvertently leave the roadway. The guardrail is mounted on posts and acts mostly in tension when impacted, however, there is some beam action. The center of the guardrail is mounted at 21 inches to provide a reactionary force near the center of gravity height of most vehicles.

When working properly, the guardrail smoothly redirects the errant vehicle away from roadside hazards such as trees, poles, large rocks and/or severe slopes.

The posts can be placed by drilling and backfilling or may be driven if soil conditions permit. W-beam guardrail is through bolted to the posts and all new installations require an offset block. The offset block minimizes wheel snagging when the system is impacted.

Since a guardrail system depends largely on tension to redirect errant vehicles, anchorage must be achieved at both end terminations. Upstream ends almost always require a crashworthy terminal with some type of cable taking tensile forces to ground at the first post. Downstream ends can sometimes be anchored with turndown sections on one-way facilities and when impacts from opposing traffic are unlikely. If impacts are likely, a crashworthy terminal must be used. Terminals and or end-treatments are discussed in the section with the same name.

Description of failure conditions/ when the system does not perform as intended:

There are two major ways guardrails fail:

- rupture of rail element
- excessive post displacement or premature post failure.

Rail element rupture almost always occurs at or near a splice with a net section failure or because of stress concentrations at the posts. Excessive deflections or premature post breakage can cause pocketing or ramping to impacting vehicles. Rupture allows vehicles into hazards and ramping can cause rollover.

Excessive post deflection is almost always caused by poor soil conditions. Premature post breakage is caused by post defects. Post defects can be rotor knots near ground level. Degradation due to insects foraging may be a causative factor in premature post breakage.



Figure 1-1: Flattened rail



Figure 1-2: Ruptured rail



Figure 1-3: Torn rail

Round wood posts:

The round wood posts are normally 7 inches in diameter and 6'3" in overall length. This allows 3" rounded top on the post.

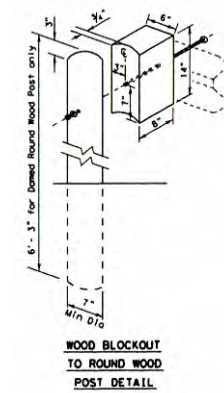


Figure 1-4: Round wooden post



Figure 1-5: Guardrail with round wooden post that failed.



Figure 1-6: Fractured wooden post

Steel post

The steel posts are normally W6 x 8.5 or W6 x 9. Note that post breakage is not likely. Posts can buckle in lateral torsion



Figure 1-7: Steel post system that performed as intended

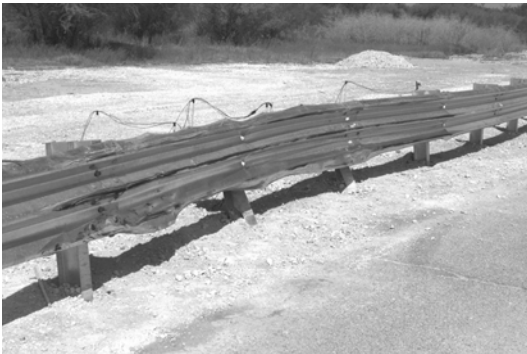


Figure 1-8: Steel post system that did not perform as intended

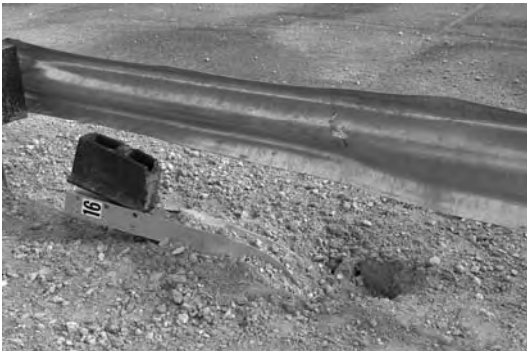
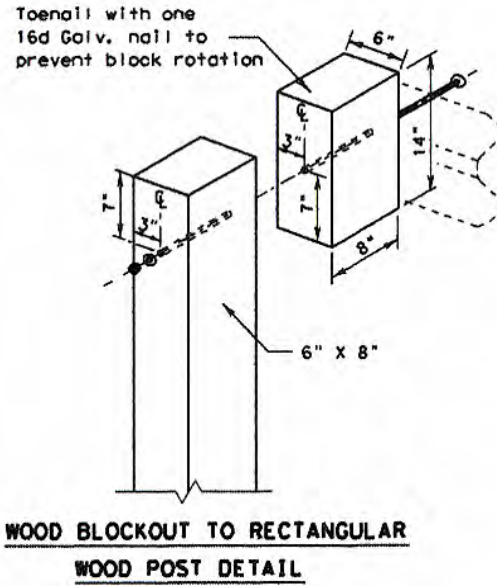


Figure 1-9: Damage to a steel post system – bend post

Rectangular wood posts:

The rectangular wood posts are normally 6 x 8 inches in diameter and 6'3" in overall length. This allows 3" top on the post.



**WOOD BLOCKOUT TO RECTANGULAR
WOOD POST DETAIL**

2. SMALL SIGNS AND SUPPORTS (<16 ft²)

How the system functions:

Small sign supports are designed to give way to an errant vehicle impacting the sign installation by either breaking away, uncoupling by means of a slip plane or yielding by permitting failure of the material the support is constructed of or the material the support is connected together with. Sign supports may be either uni-directional or multi-directional in safety performance. When impacted by an errant vehicle, the sign installation should yield to vehicles traveling 22 mph or greater and at an impact angle between 0 to 20 degrees for uni-directional performance. Multi-directional installations should not be sensitive to the impact angle at which they are struck.

To ensure predictable and safe displacement of a small breakaway sign support, select excerpts from *American Association of State Highway Transportation Officials (AASHTO) "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, 4th Edition, 2001"* are presented below:

- Substantial remains of breakaway supports shall not project more than 4 in above a line between the straddling wheels of a vehicle on 6 ft centers. The line connects any point on the ground surface on one side of the support to a point on the ground surface on the other side, and it is aligned radially or perpendicular to the centerline of the roadway.
- All breakaway supports in multiple support sign structures are considered as acting together to cause the occupant velocity at impact, unless the following items are met:
 - each support is designed to independently release from the sign panel,
 - the sign panel has sufficient torsional strength to ensure this release, and

- the clear distance between supports is greater than 84 in.
- For multipost breakaway roadside sign supports, the posts shall have enough rigidity to properly activate the breakaway device.
- The slip base breakaway device shall be oriented in the direction that ensures acceptable dynamic performance.



Figure 2-1: Concrete riprap around sign support

Description of failure conditions/ when the system does not perform as intended:

2.1 Universal Anchor System - Type A

The Universal Anchor System - Type A, small roadside sign support(s) may be used with either fiberglass (normally yellow or grey) or thin wall tube supports. The anchor stub(s) may be anchored in either a concrete foundation, approved foam backfill or cement stabilized soil or bolted down with

four 16 mm x 102 mm bolts to an unreinforced concrete footing. The maximum allowable sign panel area is 16 ft².

Both support types when impacted by an errant vehicle, may yield to the vehicle by either pulling out of the ground anchor tube, fracturing the tube support near the top of the ground anchor tube or by collapsing the tube cross section.

Improper impact performance would be demonstrated by the sign support failing to yield or do so in such a manner as to cause the support or sign panel to penetrate into the occupant compartment from any surface of the vehicle. In addition, the ground stub and/or its foundation should not be pulled or displaced from the soil.

2.2 Texas Universal Triangular Slip Base

The Texas Universal Triangular Slip Base, small roadside sign support(s) may be used with either a 2.5 in diameter schedule 10 or schedule 80 thin wall tube supports. The stub post(s) are anchored in non-reinforced concrete foundation or approved foam backfill. The maximum allowable sign panel area is 16 ft² for schedule 10 tube and 30 ft² for schedule 80 tube.

Three bolts clamp the individual slip base components together. When impacted these bolts are forced out of slots in the base. The support(s) yield to the vehicle by allowing the top support to release from the stub post by pushing out the three bolts clamping the upper and lower section together and thus releasing the slip base. It has been observed in the field that the schedule 10 support type may bend over rather than release from the slip base. This type of performance has not proven to be a hazard to the motorist but should be noted during inspection of the installation.

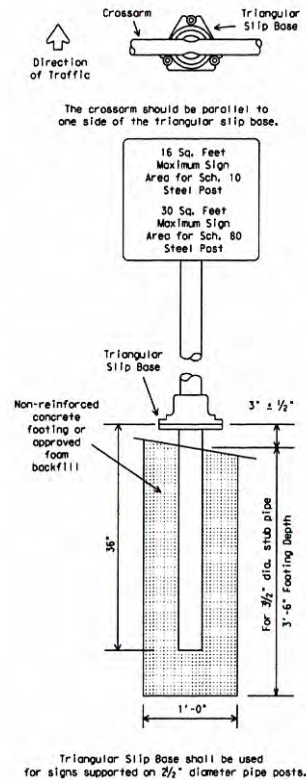


Figure 2-2: Triangular slip base

Improper impact performance would be demonstrated by the sign support failing to yield or do so in such a manner as to cause the support or sign panel to penetrate into the occupant compartment from any surface of the vehicle. A slip base support that does not separate from the slip base stub post and may be considered “locked up” is considered a performance failure. The unit should be disassembled and examined to determine if the proper hardware was provided during initial installation. If available, a torque wrench should be used to attempt to estimate the assembly torque used during installation. In addition, the ground stub and/or its foundation should not be pulled or displaced from the soil.



Figure 2-3: Schedule 10 Triangular slip base that did not perform as intended.



Figure 2-4: Slip Base activated



Figure 2-5: Slip Base did not activate

2.3 Perforated Square Metal Tubing (Driveable) - Type U

Perforated square metal tubing small roadside sign support(s) are constructed of 2.0 in square tube fabricated from 12 gage steel. The anchor stub protrudes 2.0 in above grade. The anchor stub(s) are anchored in a non-reinforced concrete foundation, approved foam backfill or cement stabilized soil. The maximum allowable sign panel area is 10 ft².

A proprietary corner bolt and flanged washer nut secure the support to the ground anchor stub. When impacted, the support(s) yield to the vehicle by allowing the top support to release from the ground stub by fracturing the cross-section of the support at or near the top of the ground and laying over.

Improper impact performance would be demonstrated by the sign support failing to yield or do so in such a manner as to cause the support or sign panel to penetrate into the occupant compartment from any surface of the vehicle. In addition, the ground stub and/or its foundation should not be pulled or displaced from the soil.



Figure 2-6: U-channel system that performed as intended



Figure 2-7: U-channel system that did not perform as intended.

2.4 Wedge Anchor Thin Wall (Driveable) - Type A

Type A, wedge anchor thin wall tube small roadside sign support(s) are constructed of 2.38 in round tube fabricated from 13 gage steel. A wedge formed from 11 gauge galvanized steel is driven between the wall of the support and the anchor stub to secure the installation. The anchor stub protrudes approximately 2.0 in above grade. The support(s) are anchored in a non-reinforced concrete foundation, approved foam backfill or cement stabilized soil. The maximum allowable sign panel area is 10 ft².

When impacted, the support(s) yield to the vehicle by allowing the top support to release from the ground stub by pulling out of the ground anchor tube or by collapsing the tube cross section.

Improper impact performance would be demonstrated by the sign support failing to yield or do so in such a manner as to cause the support or sign panel to penetrate into the occupant compartment from any surface of the vehicle. The ground stub and/or its foundation should not be pulled or displaced from the soil.

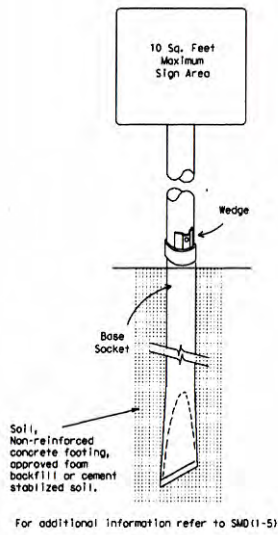


Figure 2-8: A socket base



Figure 2-11: Fiberglass post socket system that did not perform as intended



Figure 2-9: Schedule 10 socket system that performed as intended



Figure 2-10: Fiberglass post and socket system that performed as intended

3. LARGE ROADSIDE SIGNS (>16 FT²)

How the system functions:

Large sign supports are designed to give way to an errant vehicle impacting the sign installation by uncoupling through means of a slip plane (slip base) near ground level and by permitting material failure of a perforated hinge fuse plate connecting the upper and lower support posts together. Due to the mass of the large support size, the support member hinge fuse plate mechanism near the base of the sign panel is necessary. The large sign supports are uni-directional in safety performance. When impacted by an errant vehicle, the sign installation should yield to vehicles traveling 22 mph or greater and at an impact angle between 0 to 20 degrees.

To ensure predictable and safe displacement of the breakaway sign support, select excerpts from *American Association of State Highway Transportation Officials (AASHTO) "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, 4th Edition, 2001"* are presented below:

- Substantial remains of breakaway supports shall not project more than 4 in above a line between the straddling wheels of a vehicle on 6 ft centers. The line connects any point on the ground surface on one side of the support to a point on the ground surface on the other side, and it is aligned radially or perpendicular to the centerline of the roadway.
- For multipost breakaway roadside sign supports, the following shall be required to meet satisfactory breakaway performance:
- The hinge shall be at least 84 in above the ground so that no portion of the sign or upper section of the support is likely to penetrate the windshield of an impacting car or medium sized truck.
- A single post, spaced with a clear

distance of 84 in or more from another post, shall have a mass no greater than 44 lb/ft. The total mass below the hinge, but above the shear plate of the breakaway base, shall not exceed 600 lb. For two posts spaced with less than 84 in clearance, each post shall have a mass less than 17 lb/ft.

- No supplemental signs shall be attached below the hinges if such placement is likely to interfere with the breakaway action of the support post or if the supplemental sign is likely to penetrate the windshield of an impacting vehicle.
- All breakaway supports in multiple support sign structures are considered as acting together to cause the occupant velocity at impact, unless the following items are met:
 - Each support is designed to independently release from the sign panel,
 - The sign panel has sufficient torsional strength to ensure this release, and
 - the clear distance between supports is greater than 84 in.
- For multipost breakaway roadside sign supports, there shall be sufficient strength in the connections between the post and the sign to allow the hinge system to function on impact.
- For multipost breakaway roadside sign supports, the posts shall have enough rigidity to properly activate the breakaway device.

The slip base breakaway device shall be oriented in the direction that ensures acceptable dynamic performance.



Figure 3-1: Stub heights should be less or equal to 4” to minimize the potential for vehicle snagging at the undercarriage. Each support has a specific stub height requirement – refer to the standard drawings for further detail.



Figure 3-4: When breakaway sign bases are buried, additional force may be required to activate the breakaway base. Care should be taken during initial grading and maintenance activities.



Figure 3-2: The grading of surrounding terrain should enable an errant vehicle to pass over any non-breakaway portion of the post installation. To ensure this, the AASHTO Roadside Design guide provides a recommendation as shown in Figure 3-3.

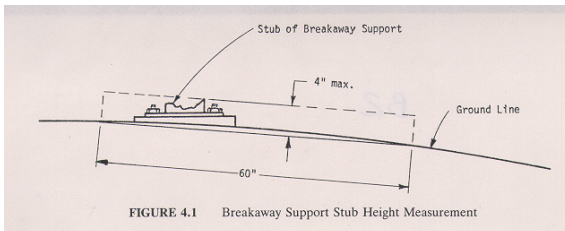


Figure 3-3: The AASHTO Roadside Design Guide recommends that stub heights be measured over a 6 foot cord as shown in the diagram.

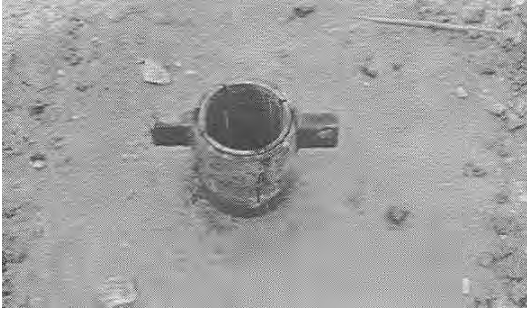


Figure 3-5: Example of post that pulled out of the socket



Figure 3-8: Fiberglass post socket system that did not perform as intended

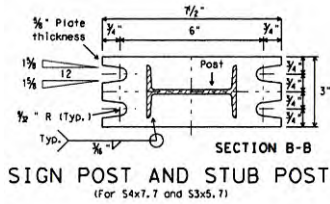


Figure 3-6: The rectangular slip base



Figure 3-9: U-channel system that performed as intended



Figure 3-7: Rectangular slip base that performed as intended.



Figure 3-10: U-channel system that did not perform as intended

Description of failure conditions/ when the system does not perform as intended:

3.1 4- Bolt Slip Base

The four bolt TxDOT slip base is constructed using varying post sizes from S3x5.7 up to W12x26, depending on the sign panel area requiring support. Attached to the bottom of each support is a welded inclined plate containing four slots (2 each side) comprising the slip base mechanism. Due to the mass of the large support size required, each support member contains a perforated hinge fuse plate mechanism near the base of the sign panel is necessary. The hinge fuse plate connects the upper and lower sections of the support post together and is located on both flanges of the support.

Four bolts clamp the individual slip base components together. When impacted these bolts are forced out of slots in the base. The support(s) yield to the vehicle by allowing the top support to release from the ground support by pushing out the four bolts clamping the upper and lower section together and thus releasing the slip base. Additionally, as the slip base releases the support, the perforated hinge fuse plate fails on the impacted side of the support, bends and/or fractures on the opposite flange, and permits the support to separate from the sign panel. Typically the sign installation remains essentially upright and intact and only the bolts, keeper plate and fuse plate require replacing.

Improper impact performance would be demonstrated by the sign support failing to yield or do so in such a manner as to cause the support or sign panel to penetrate into the occupant compartment from any surface of the vehicle. A slip base support that does not separate from the slip base stub post and may be considered “locked up” is considered a performance failure. The unit should be disassembled and examined to

determine if the proper hardware was provided during initial installation. If available, a torque wrench should be used to attempt to estimate the assembly torque used during installation. Additionally, if a fuse plate fails to activate, it should be removed and its physical dimensions documented and compared to the TxDOT standard drawings. The ground stub and/or its foundation should not be pulled or displaced from the soil.



Figure 3-11: Slip Base activated



Figure 3-12: Slip Base did not activate

3.2 *Luminaire Systems on a Transformer Base*

How the system functions:

Transformer bases are cast aluminum bases constructed 15 in to 20 in high for the purpose of mounting either steel or aluminum illumination pole and mast arm assemblies.

A luminaire assembly mounted on a transformer base is designed to give way to an errant vehicle impacting the pole and base assembly by the frangible transformer base shattering upon impact. As the assembly is impacted, the base shatters permitting the vehicle to accelerate the pole and translate it ahead of the vehicle, the vehicle passes through as the pole rotates over the vehicle. The luminaire should yield to vehicles traveling 22 mph or greater and at any impact angle.

Description of failure conditions/ when the system does not perform as intended:

The transformer base fails to function by not fracturing and releasing the luminaire support. In addition, improper impact performance would be demonstrated by a transformer base “shattering” late or only partially and in such a manner as to cause the pole or mast arm to penetrate into the occupant compartment from any surface of the vehicle. The ground stub and/or its foundation should not be pulled or displaced from the soil.

4. IMPACT ATTENUATION DEVICES

4.1 QUADGUARD System

How the system functions:

The QUADGUARD system is a re-directive (non-gating) impact attenuator used to shield roadside and median hazards. The QUADGUARD is capable of protecting hazards up to 8 feet wide when the wider unit is deployed. When the device is impacted on the nose, the system collapses and crushes the foam cartridges to consume energy from the errant vehicle. The amount of collapse on the system varies with vehicle type, impact speed and impact angle. When the system is impacted on the side, the fender panels working in conjunction with the diaphragms and monorail system, redirect errant vehicles away from the shielded object.

Description of failure conditions:

Excessive deflections near the rear of the system may allow errant vehicles to contact the object being shielded. Energy absorbing modules may be displaced and be out of position for severe impacts. Undamaged modules from collapsed bays would be indicative of improperly positioned modules.

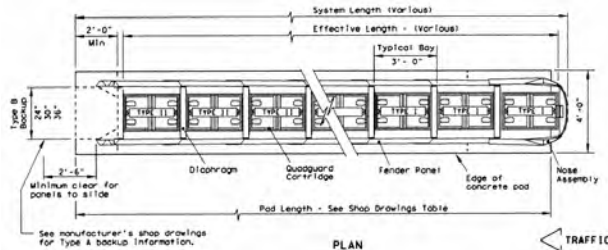


Figure 4-1: QUADGUARD System

4.2 QUADGUARD (Elite) System

How the system functions:

The QUADGUARD (Elite) system is a version of the standard QUADGUARD system that uses re-usable High Density Polyethylene (HDPE) cylinders as the energy absorbing medium. It is a re-directive (non-gating) impact attenuator used to shield roadside and median hazards. The QUADGUARD (Elite) is capable of protecting hazards up to 8 feet wide when the wider unit is deployed. When the device is impacted on the nose, the system collapses and crushes the HDPE cylinders to consume energy from the errant vehicle. The amount of collapse on the system varies with vehicle type, impact speed and impact angle. After impact, the HDPE cylinders largely self-restore to their original shape. When the system is impacted on the side, the fender panels working in conjunction with the diaphragms and monorail system, redirect errant vehicles away from the shielded object.

Description of failure conditions:

Excessive deflections near the rear of the system may allow errant vehicles to contact the object being shielded. Energy absorbing modules may be displaced and be out of position for severe impacts. Undamaged modules from collapsed bays would be indicative of improperly positioned modules.

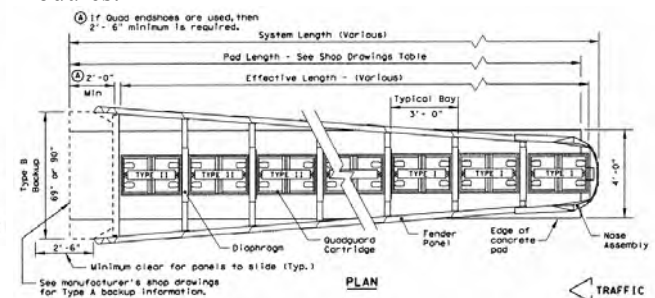


Figure 4-2: QUADGUARD Elite system

4.3 REACT (Narrow) System

How the system functions:

The REACT is a non-gating impact attenuator using High Density Polyethylene (HDPE) vertically oriented cylinders to absorb energy from errant vehicle impacts. Steel cables are attached to each side of the device for re-directive type impacts. A steel undercarriage provides anchorage of the cylinders and cables, it also provides a means of anchoring the system to the road surface.



Figure 4-3: System performed as intended

Description of failure conditions:

Excessive deflections near the rear of the system may allow errant vehicles to contact the object being shielded by the attenuator. Snagging or ramping on the front cable anchorage points could create vehicle instability.

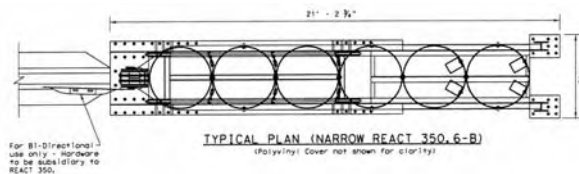


Figure 4-4: REACT Narrow System

4.4 REACT (Wide) System

How the system functions:

The REACT is a non-gating impact attenuator using High Density Polyethylene (HDPE) vertically oriented cylinders to absorb energy from errant vehicle impacts. The wide REACT uses parallel rows of HDPE cylinders mounted atop a monorail system, similar to QUADGUARD attenuators, for protecting wide objects. In addition, steel diaphragms transmit load to the base track or monorail in re-directive impacts. A steel undercarriage provides anchorage of the cylinders and provides a means of anchoring the system to the road surface.

Description of failure conditions:

Excessive deflections near the rear of the system may allow errant vehicles to contact the object being shielded by the attenuator.

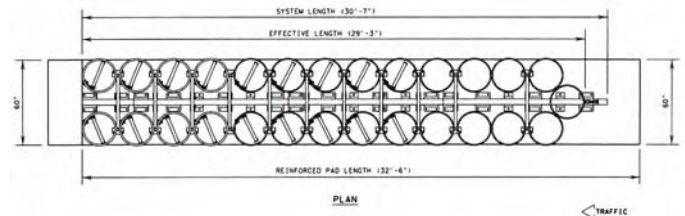


Figure 4-5: REACT Wide System

4.5 TRACC System

How the system functions:

The TRACC system is a re-directive (non-gating) impact attenuator used to shield roadside and median hazards. When the device is impacted on the nose, the system collapses and tears perforated plates within the system undercarriage to consume energy from the errant vehicle. The amount of collapse on the system varies with vehicle type, impact speed and impact angle. When the system is impacted on the side, the fender panels working in conjunction with the diaphragms and undercarriage, redirect errant vehicles away from the shielded object.

Description of failure conditions:

Excessive deflections near the rear of the system may allow errant vehicles to contact the object being shielded.

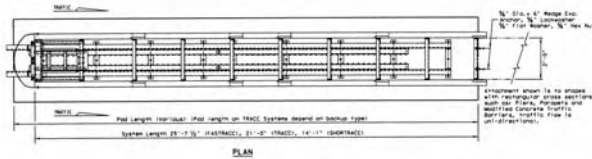


Figure 4-6: The TRACC System



Figure 4-7: System performed as intended.

4.6 Sand Barrel System

How the system functions:

Sand Barrels are provided by a number of different vendors. Sand Barrels are considered non-re-directive impact attenuators. The system operates on the principle of conservation of momentum. When an errant vehicle impacts the first sand barrel, the sand mass is accelerated to something near the velocity of the impacting vehicle. Since momentum must be conserved, the velocity of the impacting vehicle is reduced. The sand masses are staged in an increasing manner to the rear of the system. The staging is done to prevent excessive decelerations to impacting vehicle while still reducing the speed of the vehicle before it reaches the shielded object.

Description of failure conditions:

Excessive deflections near the rear of the system may allow errant vehicles to contact the object being shielded. If moisture is allowed to collect in the sand, impact performance will be degraded. The potential exists for incorrect installation. Front barrels often use some type of shelf or filler void to limit the amount of sand in the early stages of the array. Premature stoppage of vehicles coupled with excessive damage may be indicative of incorrect installation.



Figure 4-8: Sand barrels should be checked for cracks, loose or missing tops, and loss of sand.



Figure 4-9: system performed as intended

4.7 Texas Barrel System

How the system functions:

The Texas Barrel Crash Cushion is constructed using 55 gallon drums with varied crush strengths achieved by top and bottom (lid) section modification. The system is considered non-redirective. Barrels are crushed when impacted by errant vehicles and when the system is impacted other than on the nose, the system crushes and captures the errant vehicle. The Texas Barrel Crash Cushion is deployed in gore areas and medians to protect wide hazards.

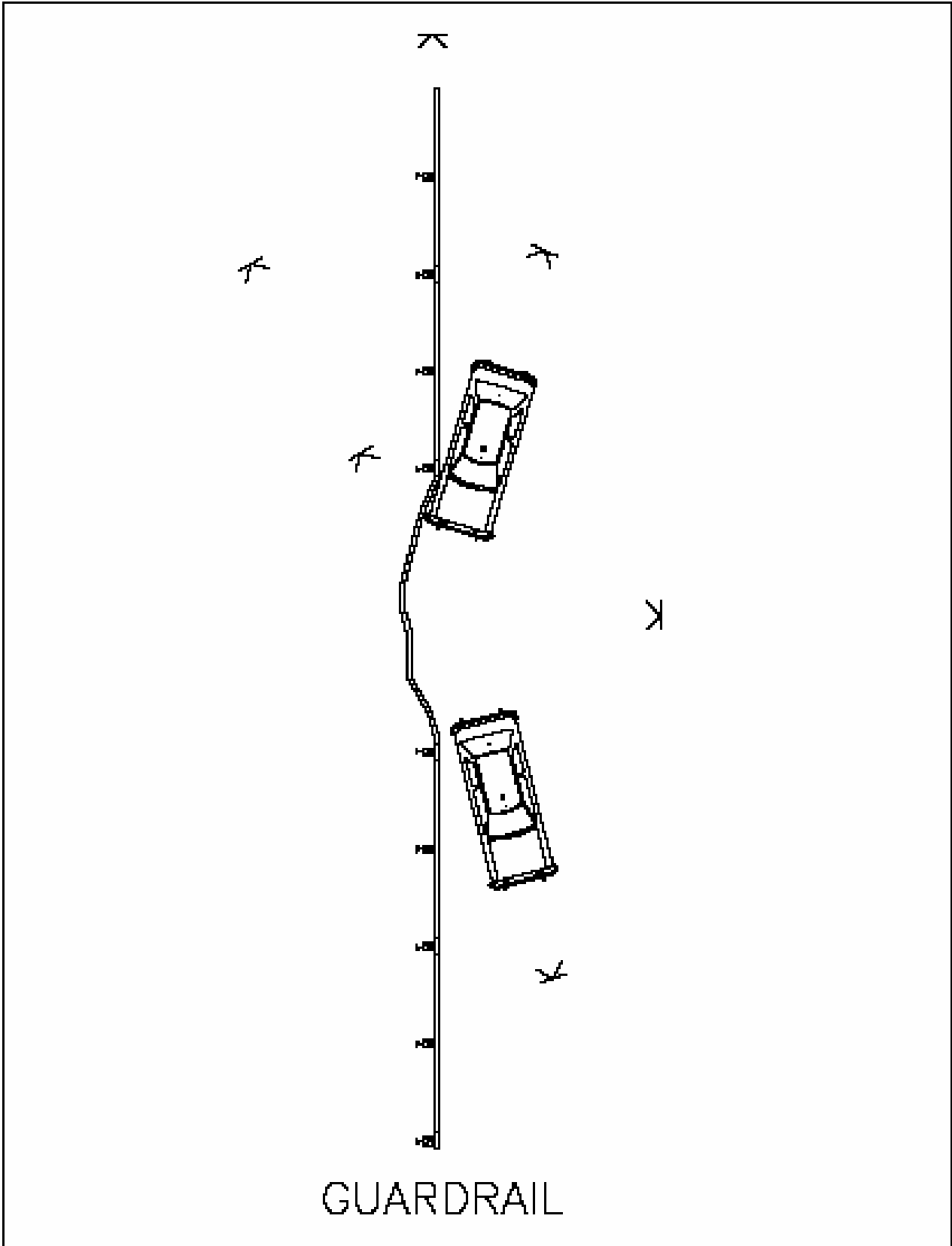
Description of failure conditions:

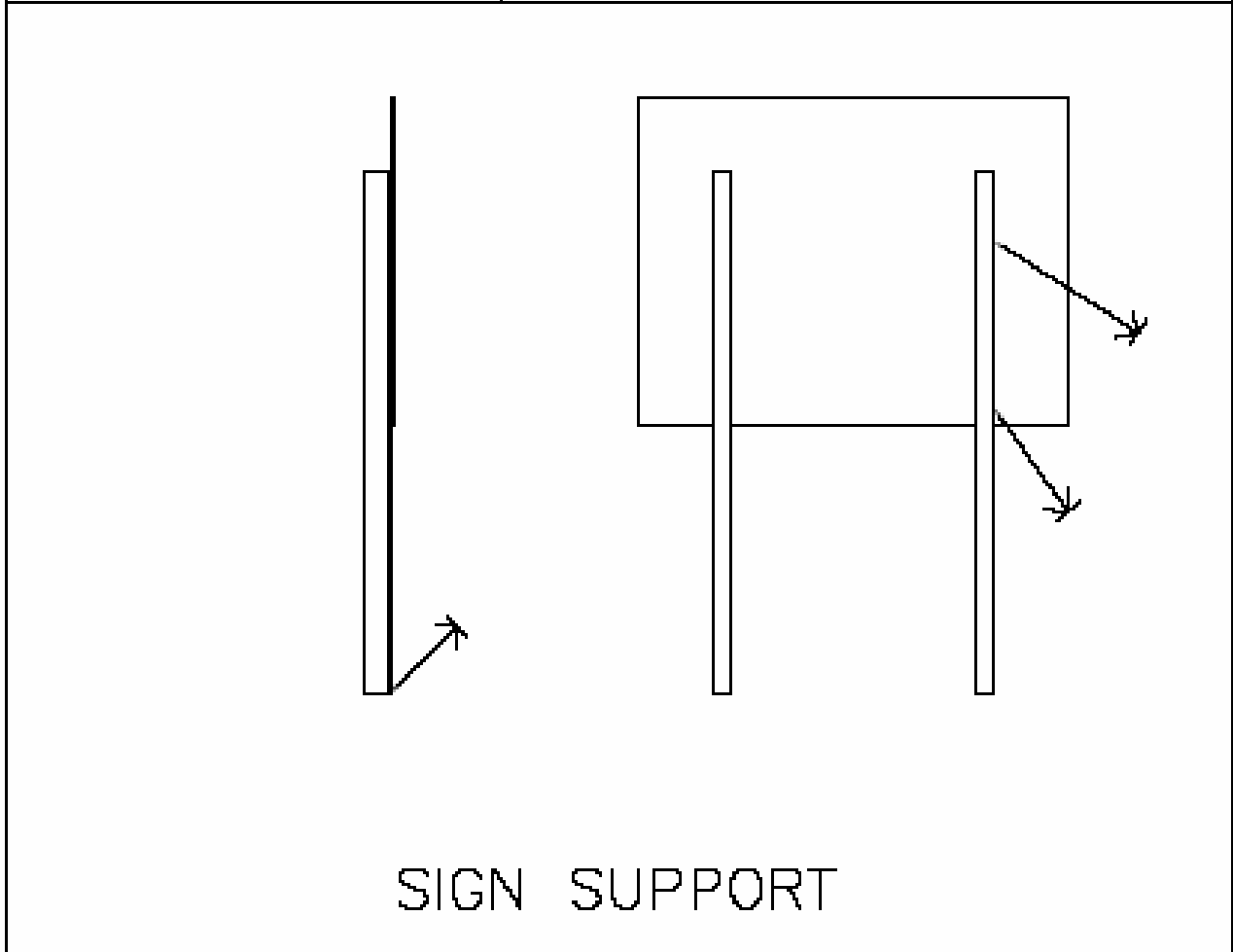
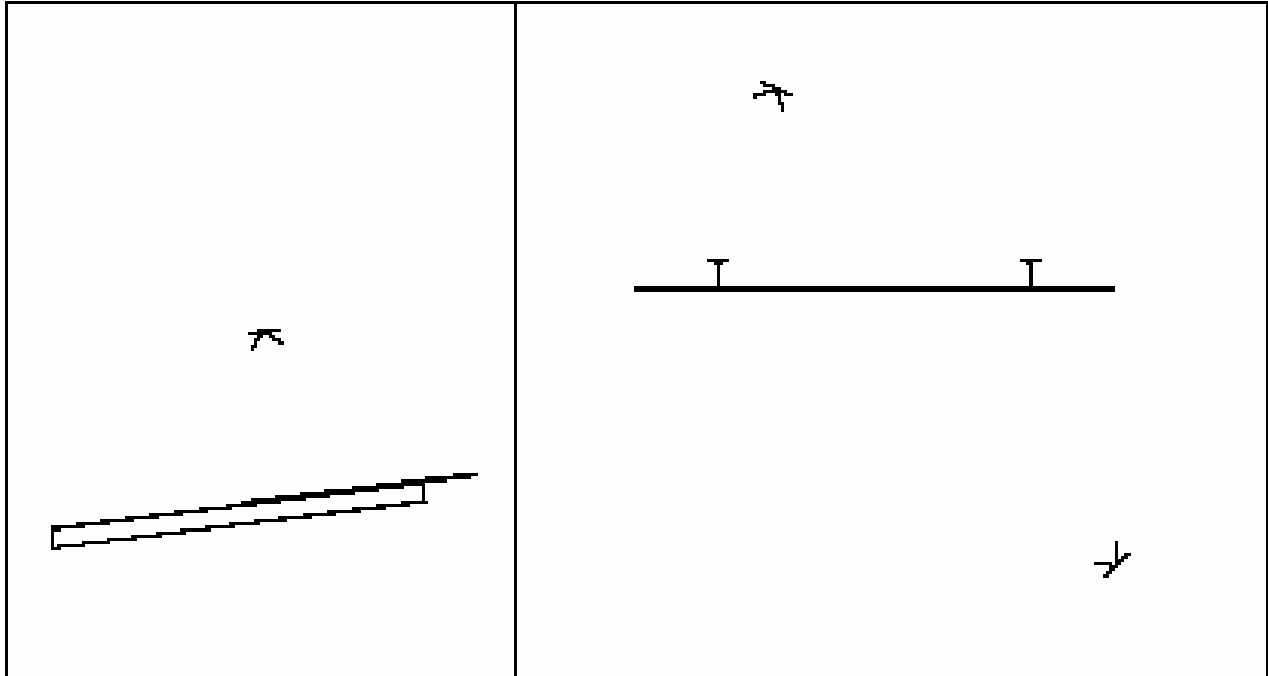
Excessive deflections near the rear of the system may allow errant vehicles to contact the object being shielded. The system has not been tested to current standards, NCHRP Report 350, and its response to pickups and sport utility trucks is limited to field experience.

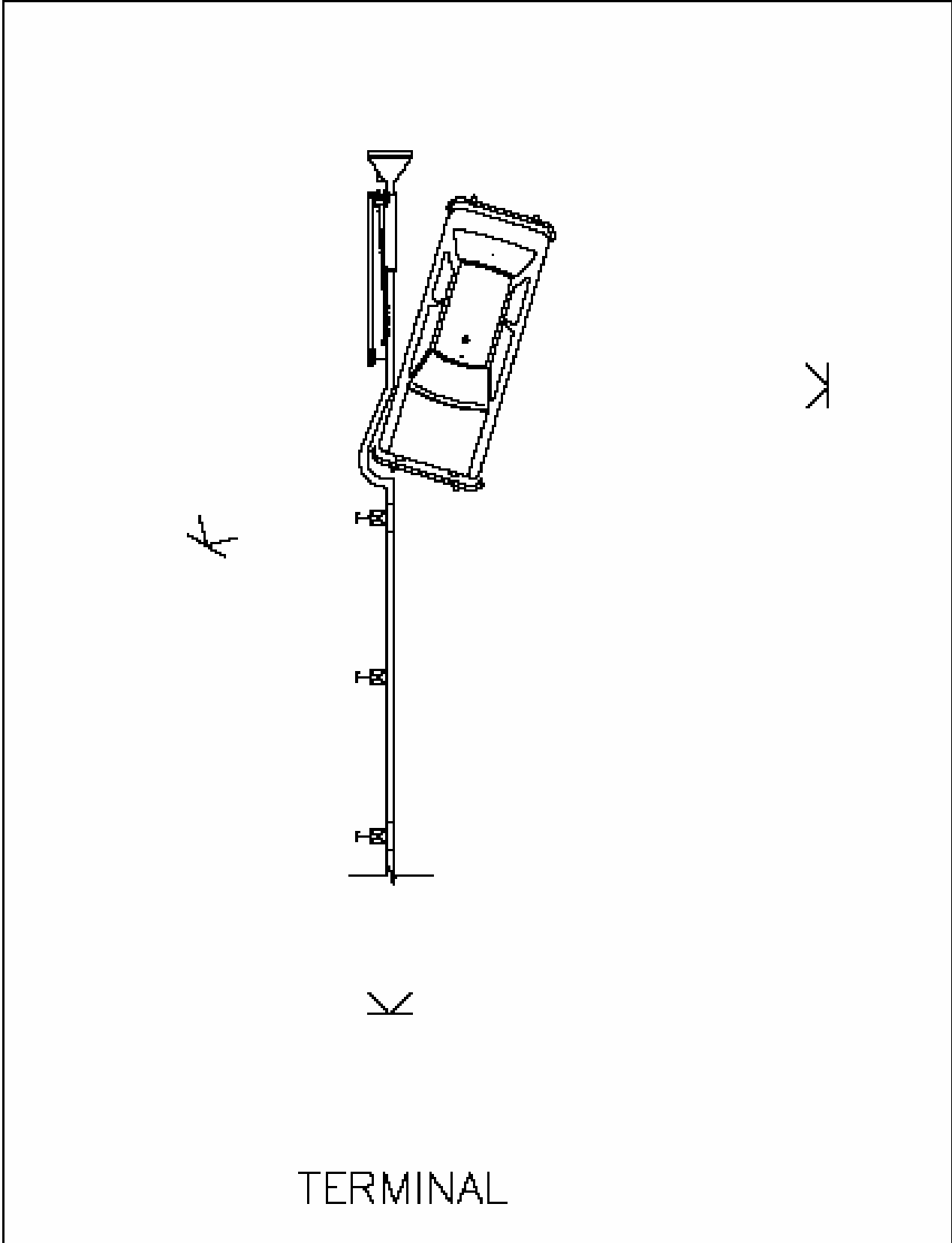


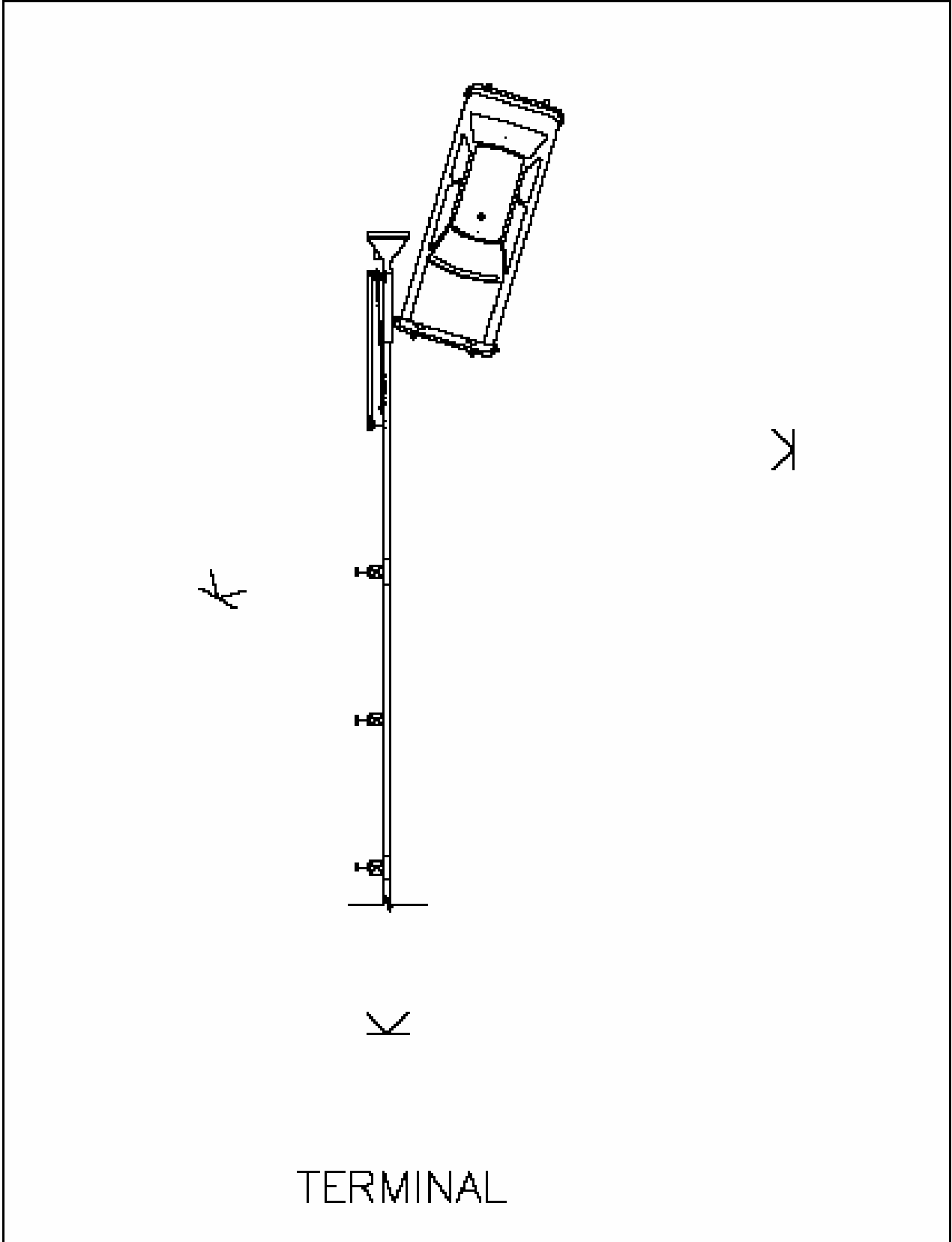
Figure 4-10: System performed as intended.

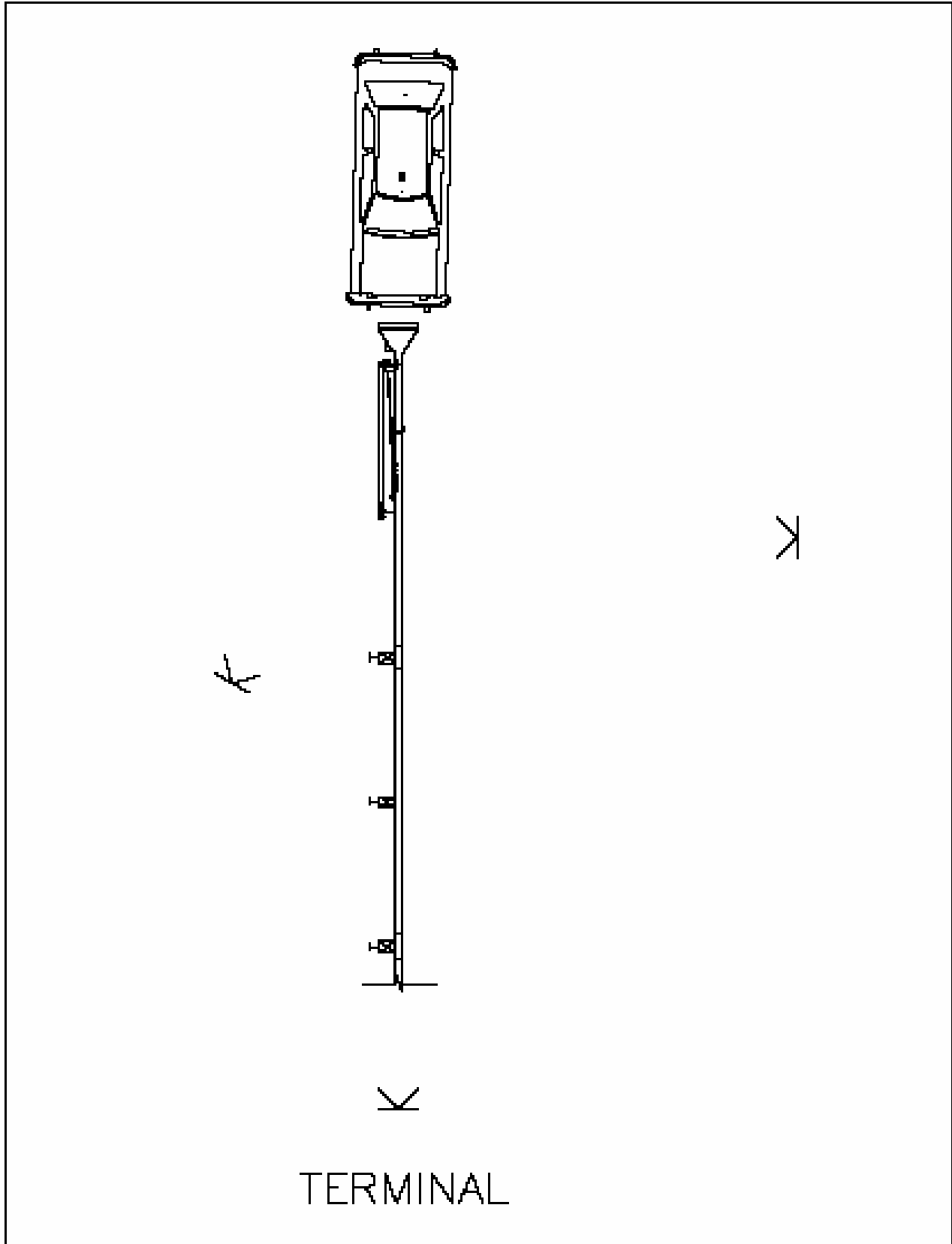
**APPENDIX G:
TRAINING MATERIALS FOR PHASE I AND II –
PHOTOGRAPH POSITIONS AND ANGLES**











**APPENDIX H:
TRAINING MATERIALS FOR PHASE II –
MICROSOFT POWERPOINT SLIDES**

**IN-SERVICE PERFORMANCE EVALUATION
OF ROADSIDE SAFETY FEATURES (TX 0-
4366)**

PILOT STUDY: PHASE II

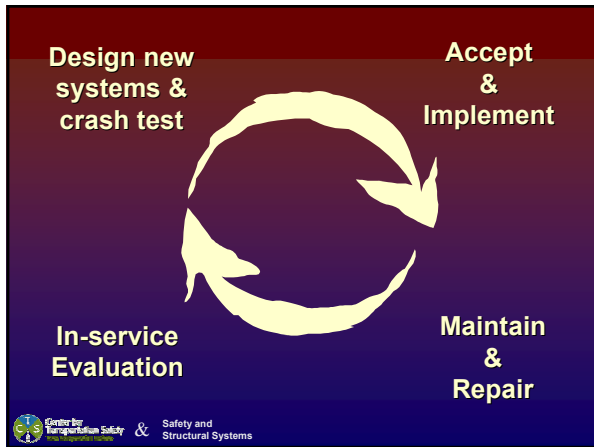
Presented by:
Ida van Schalkwyk
Tel: (979) 458 1260
Cell: (979) 218 7322
ida@tamu.edu
<http://tti.tamu.edu/cts>

Center for Transportation Safety & Structural Systems

OVERVIEW

- The pilot study
- Phase II

Center for Transportation Safety & Structural Systems



THE RESEARCH PROJECT

- **Purpose**
 - Develop process to evaluate in-service performance of roadside safety features in TX
 - Performance in the field
 - Detect problems
 - Failures
 - Applications
 - Design load exceeded
- **Pilot studies**
 - Phase I
 - Phase II

Center for Transportation Safety & Structural Systems

THE SYSTEMS

- Guardrails
- Impact attenuation devices
- End treatments


Center for Transportation Safety & Structural Systems

GUARDRAIL SYSTEMS

Center for Transportation Safety & Structural Systems

OVERVIEW

- The form
- The issues
- Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form



THE FORM

- Post type
- Post condition
- Blockout type
- Length of installation
- Installation layout
- Lateral offset
- Describe the roadside
- Height to top of rail
- Mowstrip?
- Depth of permanent deflection
- Rail condition after impact
- Length of damaged rail
- Number of damaged posts
- Damage to posts
- Impact in the transition area?



1. Post type


- Round wooden
- Rectangular wood
- Steel post





2. Post condition: Deterioration?

↓	↓	↓	↓
0% - 25%	26% - 50%	51% - 75%	76% - 100%



3. Blockout type

- None/ wood/ steel/ plastic





4. Length of installation



5. Installation layout

- > On curve
 - Outside of curve
 - Inside of curve
- > On straight

The diagram illustrates the installation layout for a vehicle on a curve and on a straight section. On the curve, two vehicles are shown: one on the 'Outside of curve' and one on the 'Inside of curve'. On the straight section, a single vehicle is shown. The background features a stylized landscape with a blue sky, green hills, and a brown ground surface.

Center for Transportation Safety & Safety and Structural Systems

6. Lateral offset

The diagram shows a cross-section of a road with a shoulder and a traveled lane. A yellow arrow points to the 'Edge of traveled lane', and a purple arrow points to the 'Edge of pavement'. A horizontal line indicates the 'Lateral offset from edge of pavement'. The background features a stylized landscape with a blue sky, green hills, and a brown ground surface.

Center for Transportation Safety & Safety and Structural Systems

7. Height to top of rail

The diagram shows a vertical post with a rail attached to its top. A vertical arrow points from the ground level to the top of the rail, labeled 'Height to top of rail'. The background features a stylized landscape with a blue sky, green hills, and a brown ground surface.

Center for Transportation Safety & Safety and Structural Systems

8. Mowstrip?

The diagram shows a cross-section of a road with a mowstrip. The background features a stylized landscape with a blue sky, green hills, and a brown ground surface.

Center for Transportation Safety & Safety and Structural Systems

9. Depth of permanent deflection?

The diagram shows two scenarios of rail deflection. In the first, a single vehicle is shown on a rail, and a vertical arrow indicates the depth of permanent deflection. In the second, two vehicles are shown on a rail, and a vertical arrow indicates the depth of permanent deflection. The background features a stylized landscape with a blue sky, green hills, and a brown ground surface.

Center for Transportation Safety & Safety and Structural Systems


10. Rail condition after impact

The diagram shows three photographs of rail conditions after impact. The first is labeled 'Flattened' and shows a rail that has been flattened. The second is labeled 'Partial tear in rail' and shows a rail with a partial tear. The third is labeled 'Ruptured: Tear all through' and shows a rail that has been completely ruptured. The background features a stylized landscape with a blue sky, green hills, and a brown ground surface.

Center for Transportation Safety & Safety and Structural Systems

11. Length of damaged rail
11.1 Number of damaged posts
11.2 Damage to posts

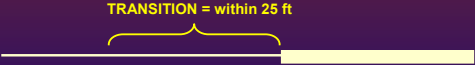

- Deflected in soil
- Bent (steel)
- Fractured (wood)



12. Impact in the transition area?


- ❑ Within 25 ft of bridge rail

TRANSITION = within 25 ft

OTHER INFO

- ❑ Did it perform as intended?
 - Remember comment & sketch!
- ❑ Photographs
 - Critical
- ❑ Maintenance cost & labor
- ❑ Accident report form
 - If available
 - Valuable info for Phase II



TRANSITIONS
Guardrail to Bridge Rail





1. **SELECT THE TYPE OF DEVICE:**

d) **TRANSITION**

W-BEAM GUARDRAIL TRANSITION
 THRIE BEAM TRANSITION


2. **DID THE SYSTEM PERFORM AS INTENDED?** (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)

YES NO




TRANSITIONS

- ❑ How is transition different from guardrail section?
- ❑ **Types**
 - W-beam transitions
 - Thrie beam transitions




W-BEAM TRANSITIONS

- Transition to
 - Flexible W-beam guardrail TO
 - Rigid / semi-rigid bridge rails
- How they work
 - Gradual stiffening through addition of posts in 25 ft adjacent to bridge rail
- To T501
 - W-beam, shoe & through bolts
- To T4
 - Embedded steel angle extending from end of concrete portion of bridge rail – Placed in front of the W-beam @ approx front of bridge rail





THRIE BEAM TRANSITIONS

- How they work
 - Transition
 - Flexible W-beam / thrie beam guardrail TO
 - Rigid / semi-rigid bridge rail
- Multiple transition sections
- Incremental stiffening of rail
 - Increased beam size
 - Beam nesting
 - Post spacing
 - Post embedment depth
- Nominal 6-inch curb used with nested thrie beam section





TRANSITIONS *(cont)*

- When they don't perform as intended
 - Excessive deflections near end of bridge rail
 - Cause snagging
 - Posts & rail displaced
 - Rigid end section of bridge rail exposed
 - Wheel and rim of vehicle
 - Vehicle instabilities
 - Potential: Large occupant compartment deformations

TRANSITIONS

- Questions?



IMPACT ATTENUATORS

Center for Transportation Safety & Safety and Structural Systems

OVERVIEW

- The form
- Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form

Center for Transportation Safety & Safety and Structural Systems

THE FORM

- Type of device
- Foundation type
- Residual / undeformed length of installation (What is left?)
- Was it properly shielding the obstacle?
- Did all the components of the crash cushion remain attached?
 - Except sand from sand barrels
- Where did impact initially occur?
 - Post number (& sketch)

Center for Transportation Safety & Safety and Structural Systems

Residual / undeformed length of installation

Center for Transportation Safety & Safety and Structural Systems

OTHER INFO

- Did it perform as intended?
 - Remember comment & sketch!
- Photographs
 - Critical
- Maintenance cost & labor
- Accident report form
 - If available
 - Valuable info for Phase II

Center for Transportation Safety & Safety and Structural Systems

END-TREATMENTS (SGT, GET)

Center for Transportation Safety & Safety and Structural Systems


OVERVIEW

- The form
- The issues
- Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form





THE FORM


- Type of device
- Foundation tubes
 - Exposed?
 - Height?
- Mowstrip?
- Height to top of rail?
- Number of damaged posts
- Where did impact initially occur?
 - Post number (& sketch)
- Was the device flared?
 - Describe & sketch (take photo if you can)
- Describe roadside




Foundation tubes

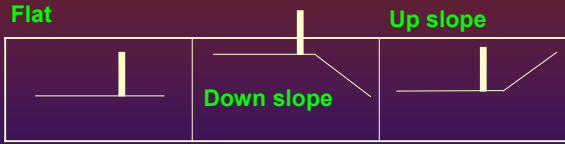
Height to top of rail




Height to top of rail



Describe the roadside





Flat Down slope Up slope



OTHER INFO


- Did it perform as intended?
 - Remember comment & sketch!
- Photographs
 - Critical
- Maintenance cost & labor
- Accident report form
 - If available
 - Valuable info for Phase II







CONCLUSION

- Different systems in use by TxDOT
 - In-service performance evaluation = Needed
- We looked at the different systems and discussed how we would complete the questions
 - Guardrails
 - Impact attenuation devices
 - End treatments



Safety and Structural Systems

QUESTIONS



Safety and Structural Systems

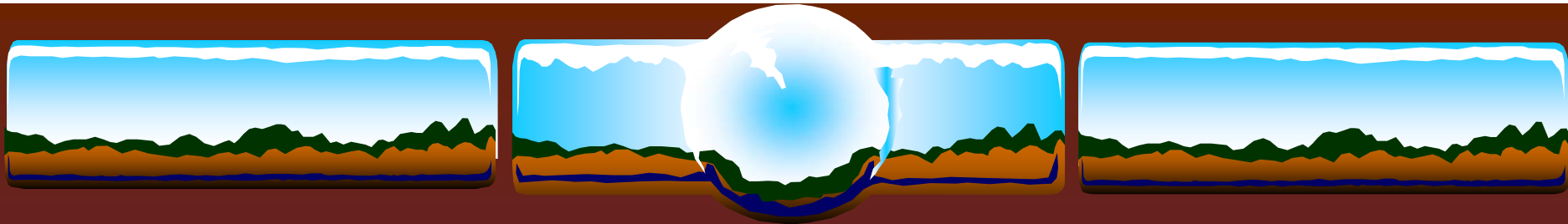


THE END



Safety and Structural Systems

**APPENDIX I:
DIGITAL COPY OF TRAINING MATERIAL
(Contents originally provided on CD-ROM with report)**



IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY FEATURES

TX 0-4366 (RMC3)

Presented by:

Dean Alberson & Ida van Schalkwyk



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



OVERVIEW

- The research project
- Topics
 - Systems
 - How they work
 - How they fail
 - Guardrails, end-terminals, signage, impact attenuation devices, transitions



**Design new
systems &
crash test**

**Accept
&
Implement**



**In-service
evaluation**

**Maintain
&
repair**



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



THE RESEARCH PROJECT

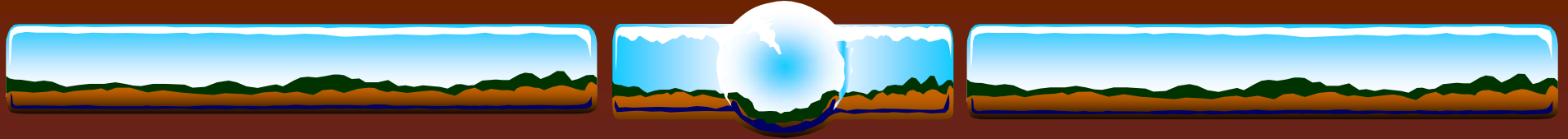
□ Purpose

- Develop process to evaluate in-service performance of roadside safety features in TX
 - Performance in the field
 - Detect problems
 - *Failures*
 - *Applications*
 - *Design load exceeded*

□ Method

- Phase I
- Phase II





THE RESEARCH PROJECT *(cont)*

□ Phase I

- Basic questions
 - Signage
 - Other: Guardrails, transitions, impact attenuation devices, end treatments
 - *Type of system?*
 - *Did it perform as intended?*
- Pilot will test basic questions

□ Phase II

- Detailed research study
- Another pilot to test Phase II questions

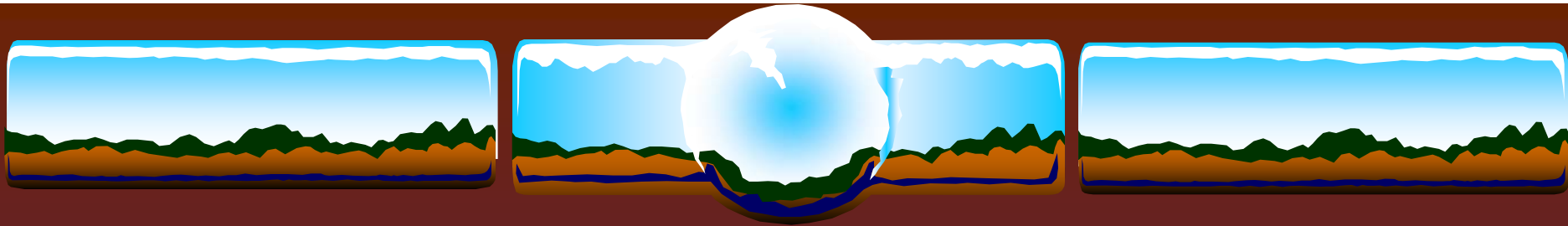




THE SYSTEMS

- Guardrails
- Transitions
- Impact attenuation devices
- End treatments
- Signs
 - Small signs
 - Large signs





GUARDRAIL SYSTEMS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



OVERVIEW

- ❑ The form
- ❑ The issues
- ❑ Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form





THE FORM

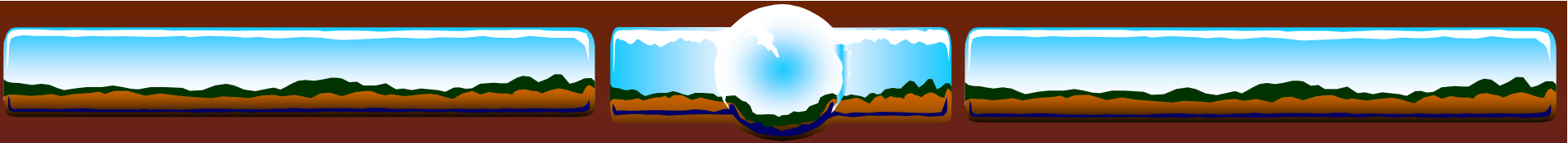
- Post type
- Post condition
- Blockout type
- Length of installation
- Installation layout
- Lateral offset
- Describe the roadside
- Height to top of rail
- Mowstrip?
- Depth of permanent deflection
- Rail condition after impact
- Length of damaged rail
- Number of damaged posts
- Damage to posts
- Impact in the transition area?



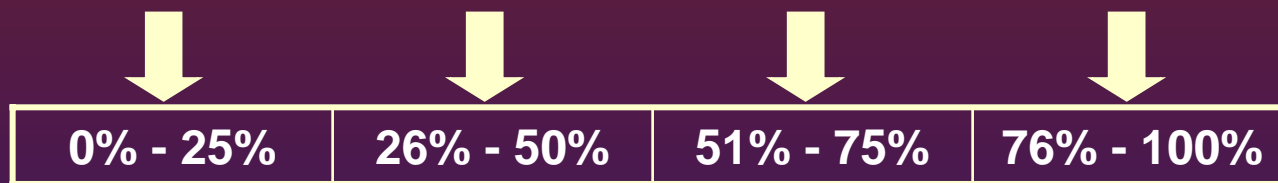
1. Post type

- Round wooden
- Rectangular wood
- Steel post





2. Post condition: Deterioration?

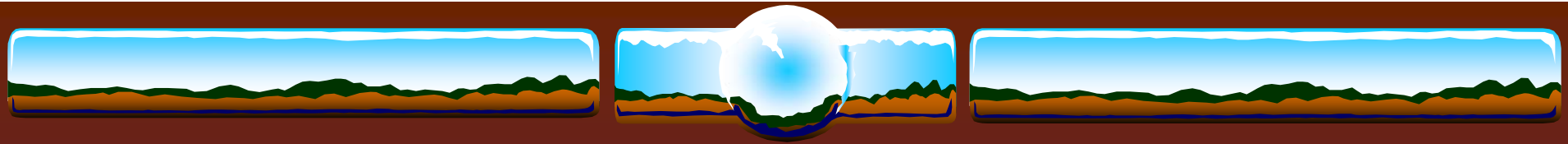




3. Blockout type

- None/ wood/ steel/ plastic





4. Length of installation



Center for
Transportation Safety
Texas Transportation Institute



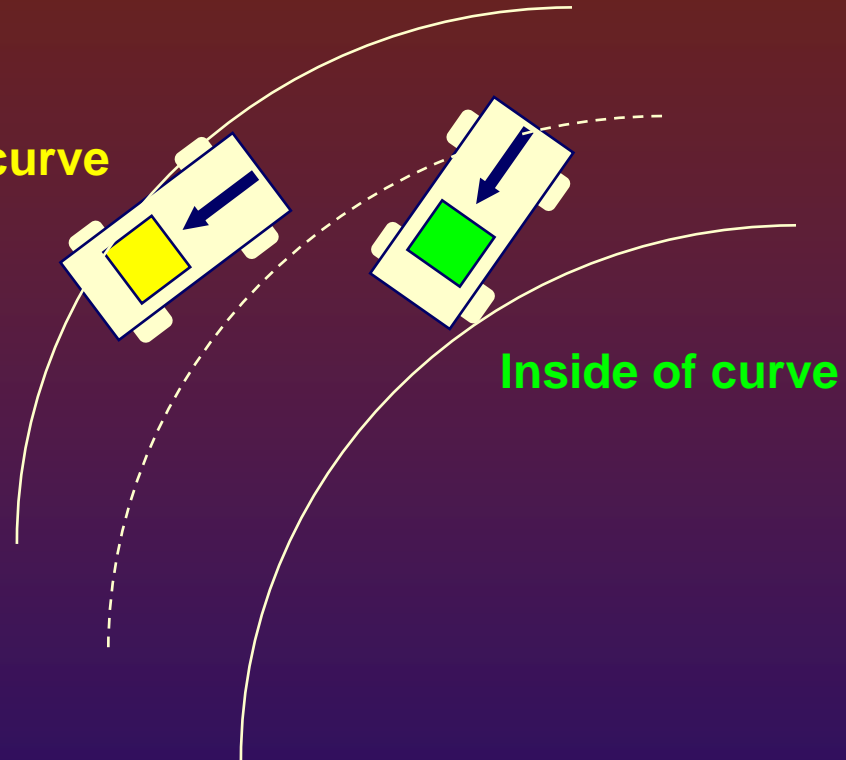
Safety and
Structural Systems



5. Installation layout

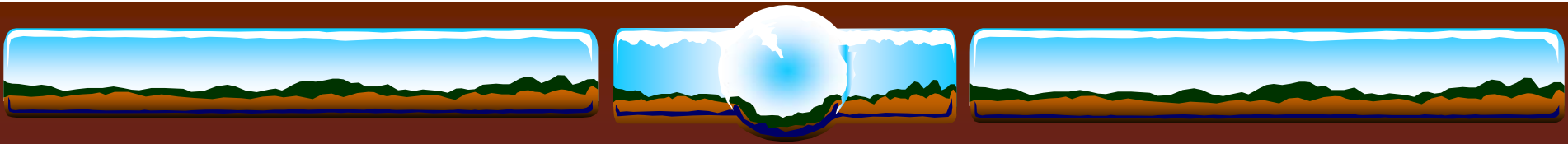
➤ On curve

Outside of curve

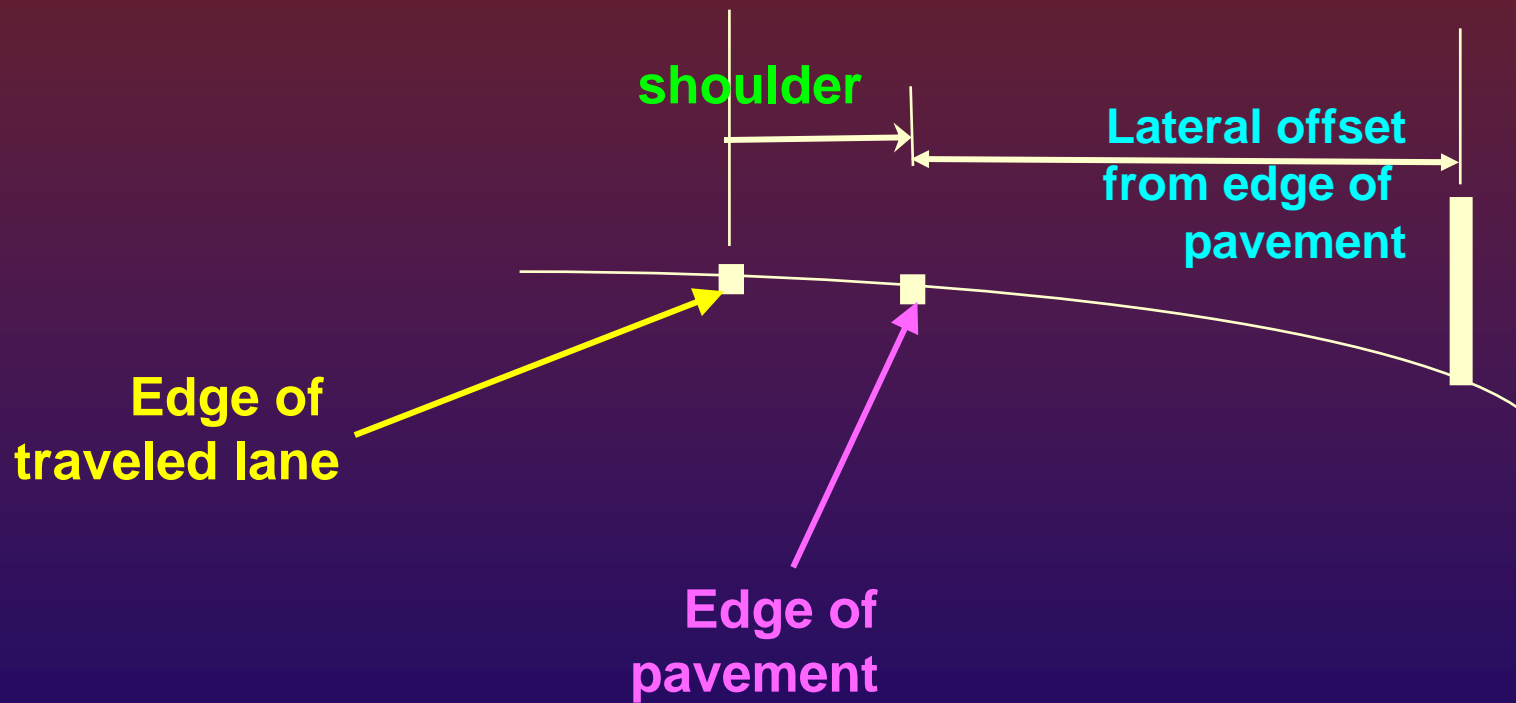


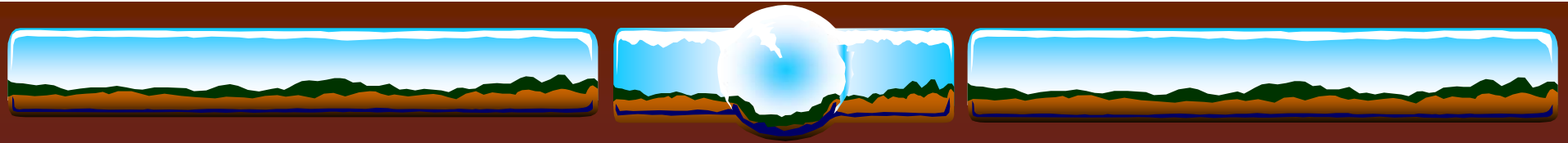
➤ On straight





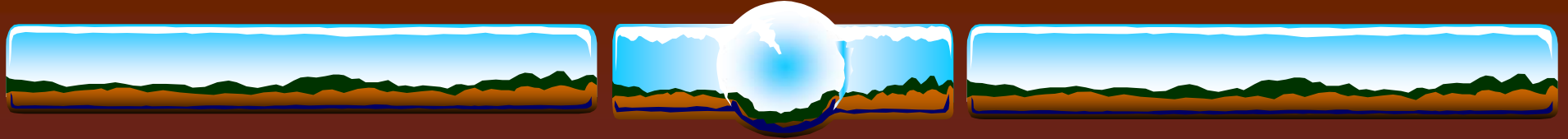
6. Lateral offset





7. Height to top of rail





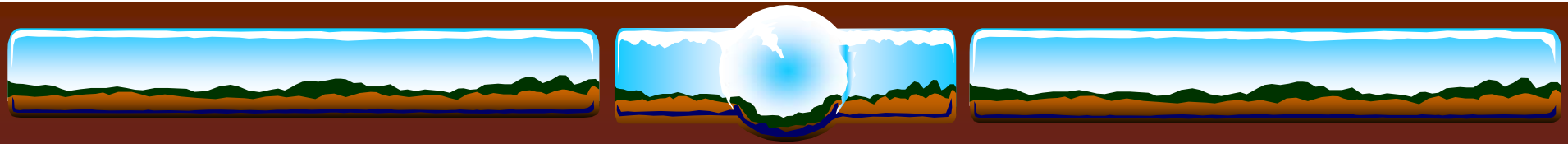
8. Mowstrip?



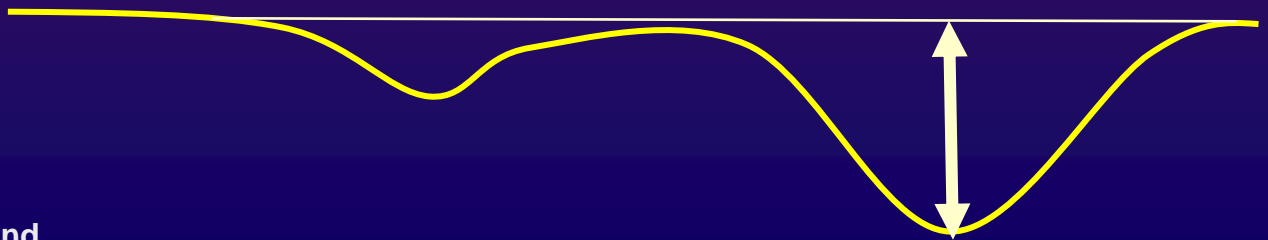
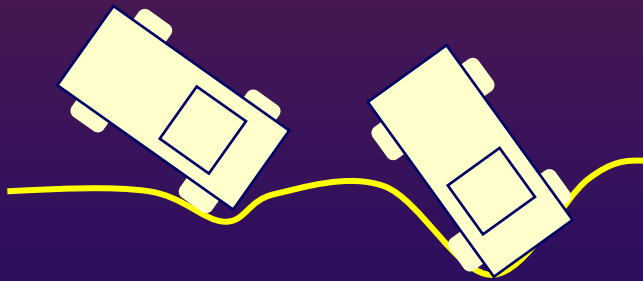
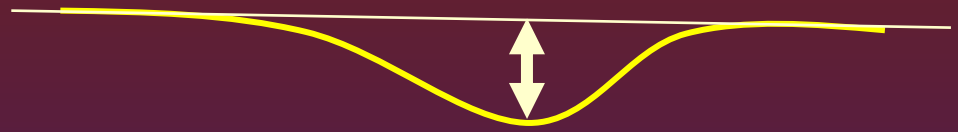
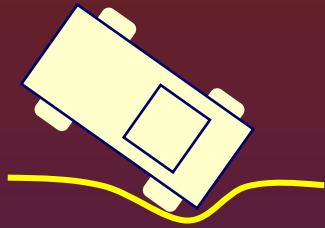
Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



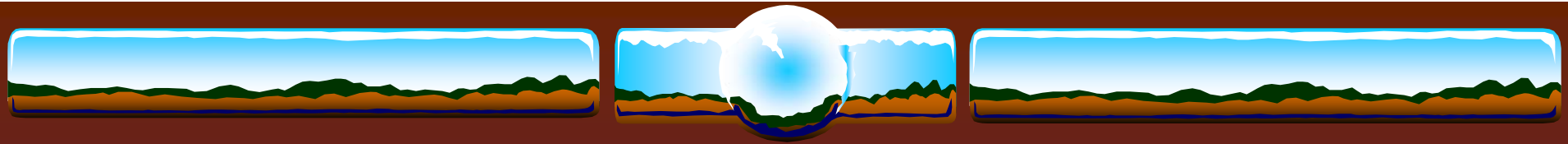
9. Depth of permanent deflection?



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



10. Rail condition after impact

Flattened

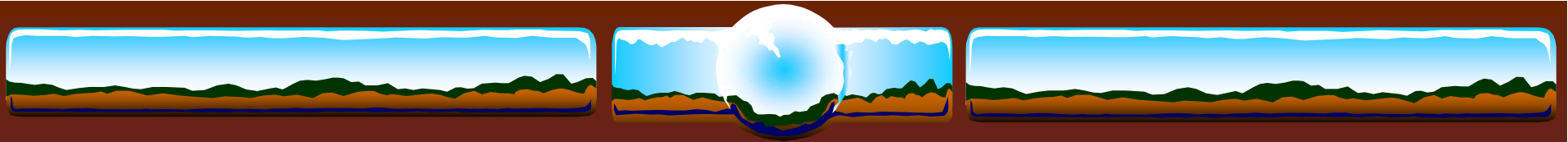


Partial tear in rail



**Ruptured:
Tear all through**





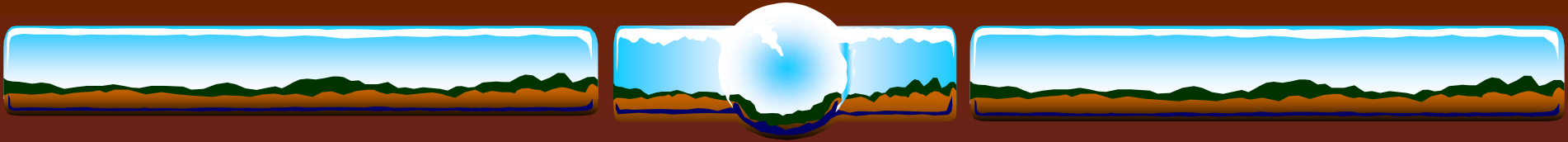
11. Length of damaged rail

11.1 Number of damaged posts

11.2 Damage to posts

- Deflected in soil
- Bent (steel)
- Fractured (wood)





12. Impact in the transition area?

- Within 25 ft of bridge rail

TRANSITION = within 25 ft

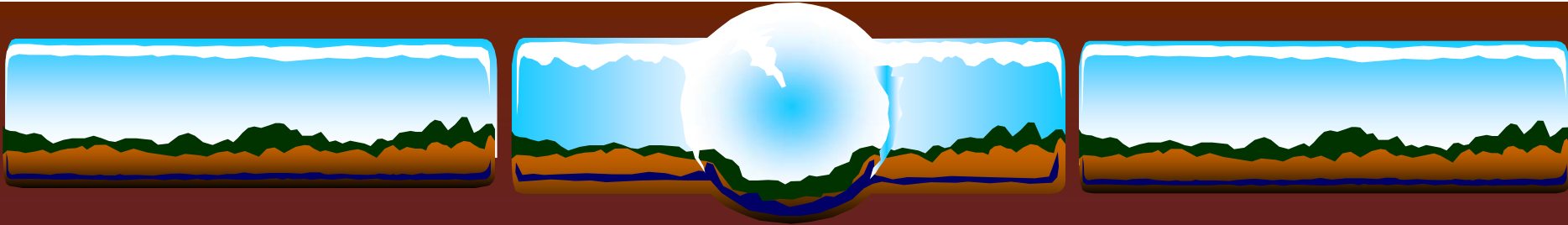




OTHER INFO

- ❑ **Did it perform as intended?**
 - Remember comment & sketch!
- ❑ **Photographs**
 - Critical
- ❑ **Maintenance cost & labor**
- ❑ **Accident report form**
 - If available
 - Valuable info for Phase II





TRANSITIONS

Guardrail to Bridge Rail



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems

1. SELECT THE TYPE OF DEVICE:

d) *TRANSITION*

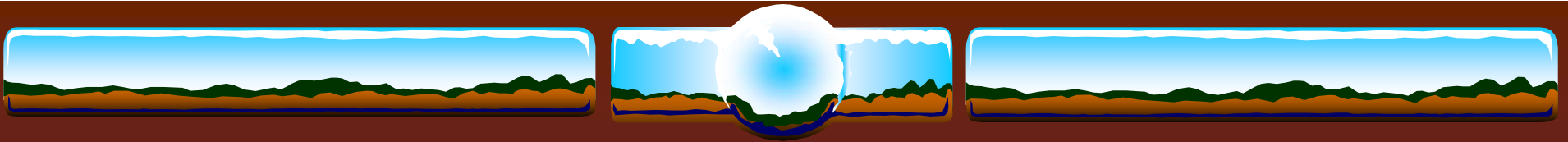
- W-BEAM GUARDRAIL TRANSITION
 THRIE BEAM TRANSITION

2. DID THE SYSTEM PERFORM AS INTENDED? (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)

YES

NO





TRANSITIONS

- How is transition different from guardrail section?
- Types
 - W-beam transitions
 - Thrie beam transitions





W-BEAM TRANSITIONS

□ Transition to

- Flexible W-beam guardrail TO
- Rigid / semi-rigid bridge rails

□ How they work

- Gradual stiffening through addition of posts in 25' adjacent to bridge rail

□ To T501

- W-beam, shoe & through bolts

□ To T4

- Embedded steel angle extending from end of concrete portion of bridge rail – Placed in front of the W-beam @ approx front of bridge rail

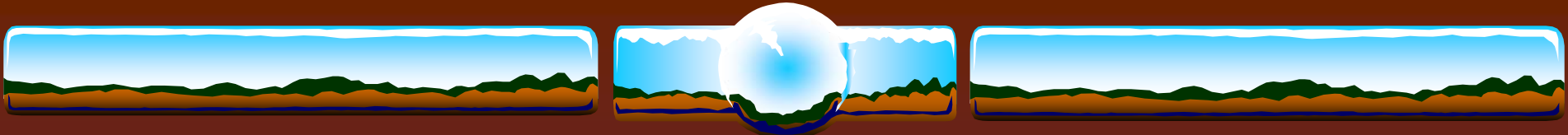




Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



THRIE BEAM TRANSITIONS

□ How they work

➤ Transition

- Flexible W-beam / thrie beam guardrail TO
- Rigid/ semi-rigid bridge rail

□ Multiple transition sections

□ Incremental stiffening of rail

- Increased beam size
- Beam nesting
- Post spacing
- Post embedment depth

□ Nominal 6” curb used with nested thrie beam section





Center for
Transportation Safety
Texas Transportation Institute



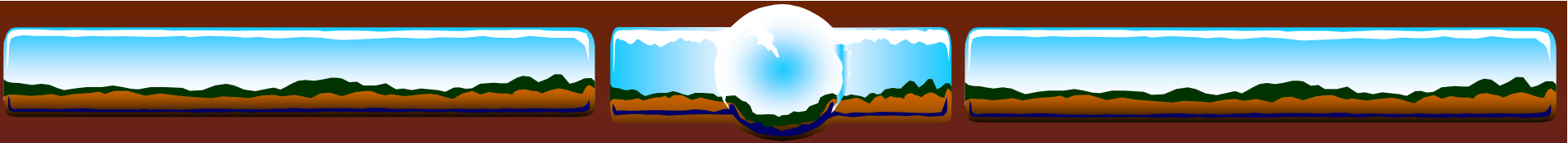
Safety and
Structural Systems



TRANSITIONS *(cont)*

- When they don't perform as intended
 - Excessive deflections near end of bridge rail
 - Cause snagging
 - *Posts & rail displaced*
 - *Rigid end section of bridge rail exposed*
 - Wheel and rim of vehicle
 - Vehicle instabilities
 - Potential: large occupant compartment deformations





TRANSITIONS

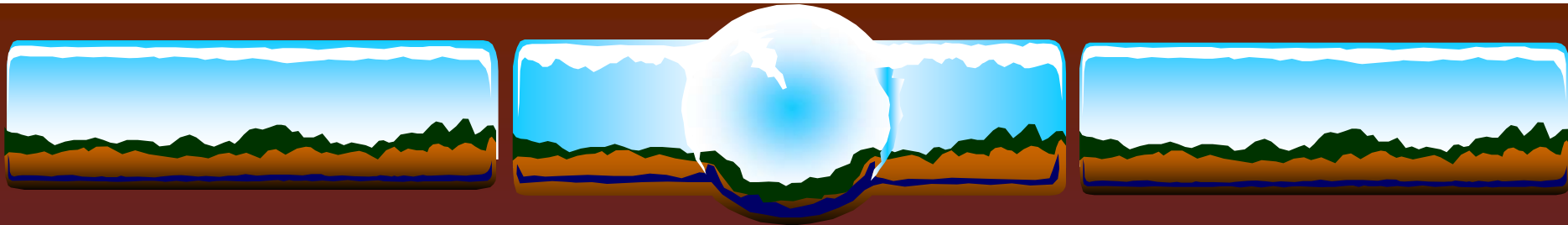
□ Questions?



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



IMPACT ATTENUATORS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems

1. SELECT THE TYPE OF DEVICE:

c) **IMPACT ATTENUATORS**

Type of device: QUADGUARD Wide SANDBARREL SYSTEM (pick)
 QUADGUARD Elite FITCH
 REACT Narrow ENERGITE
 REACT Wide TRAFFIX
 GREAT
 TX BARREL CRASH CUSHION
 TRAC
 HEXFOAM
 HYDROCELL

OTHER:

Foundation type: CONCRETE ASPHALT DIRT

OTHER:

Width of object protected:

2. DID THE SYSTEM PERFORM AS INTENDED? (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)

YES

NO





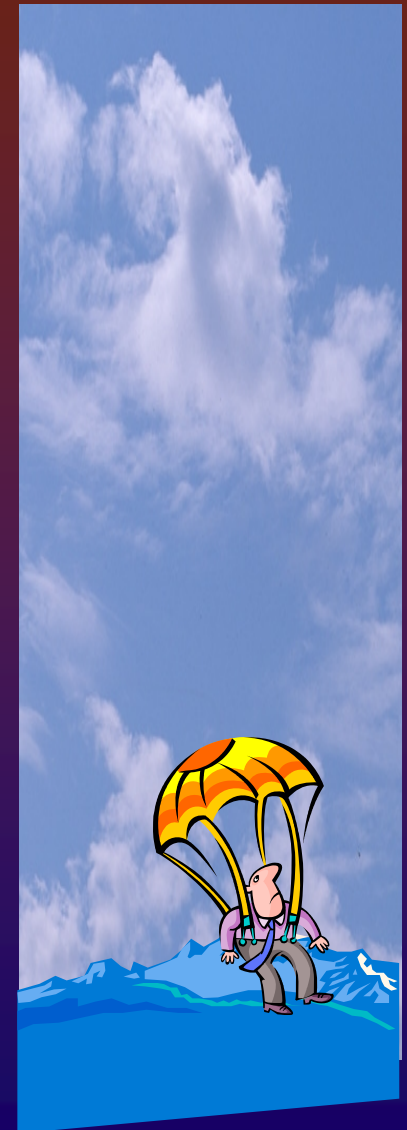
IMPACT ATTENUATORS

□ How they work

- Increases the time it takes for the vehicle to slow down (“parachute”)

□ When they don’t perform as intended

- When the vehicle made contact with the object it protected
- When the vehicle rolled over



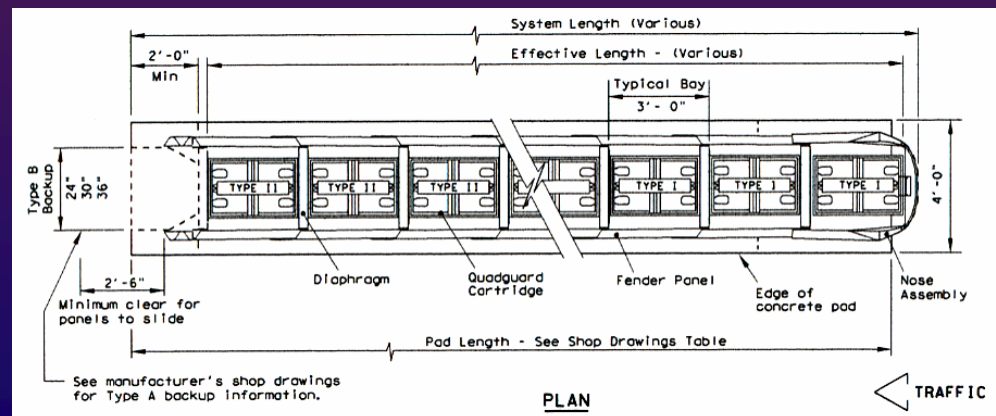
QUADGUARD

□ Redirective (non-gating)

- Shields roadside & median hazards

□ Impacted on nose

- System collapses
- Crush foam cartridges to consume energy from vehicle
- Amount of collapse
 - Vehicle type
 - Impact speed
 - Impact angle





QUADGUARD

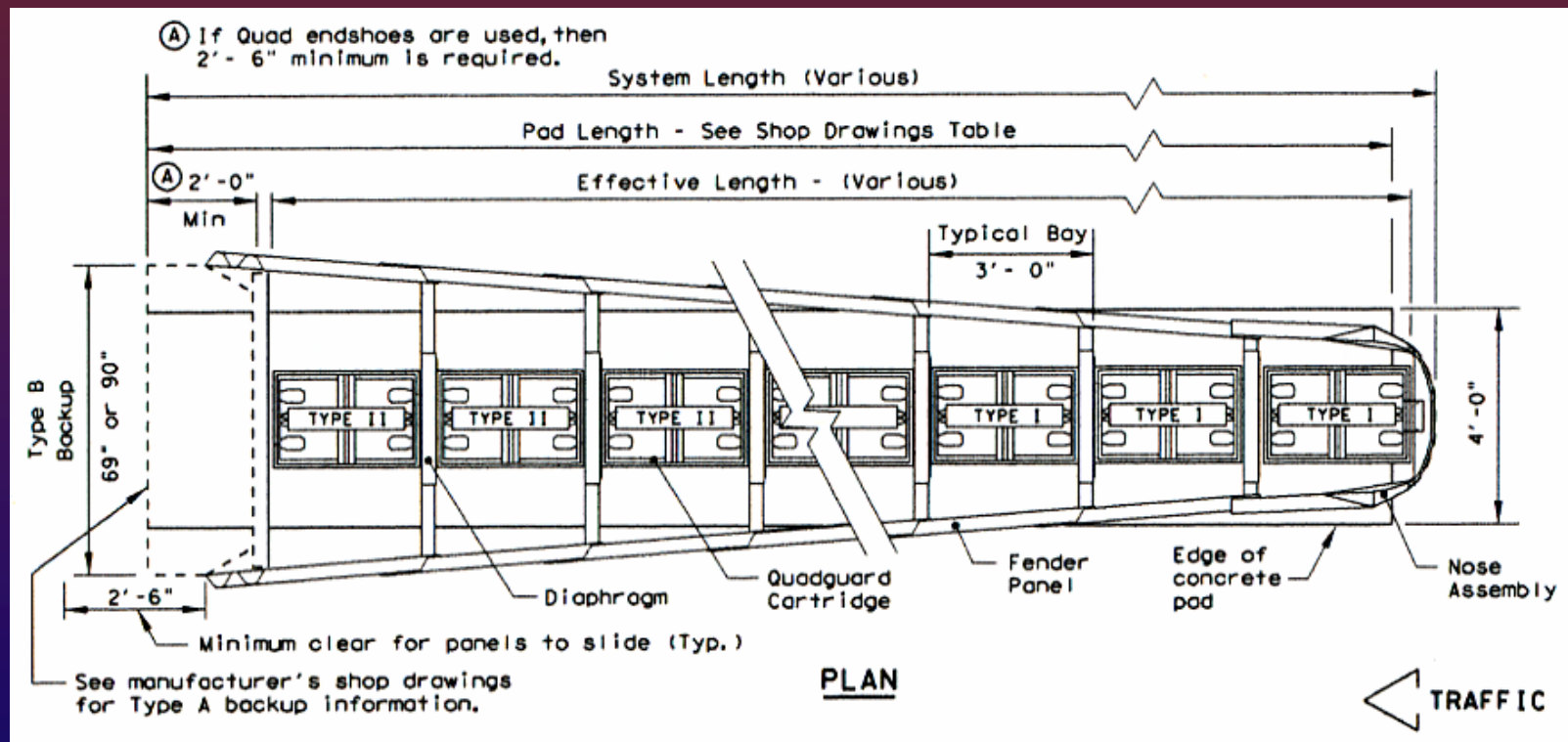
□ Impacted on side

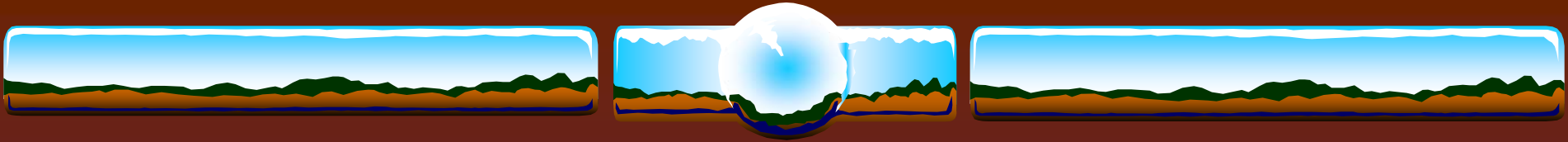
- Vehicle redirected & shielded from hazard
 - Fender panels
 - Diaphragms
 - Monorail system



QUADGUARD Wide

- Protect 8-ft wide hazards





QUADGUARD Elite



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



QUADGUARD Elite *(cont)*

□ How the system functions



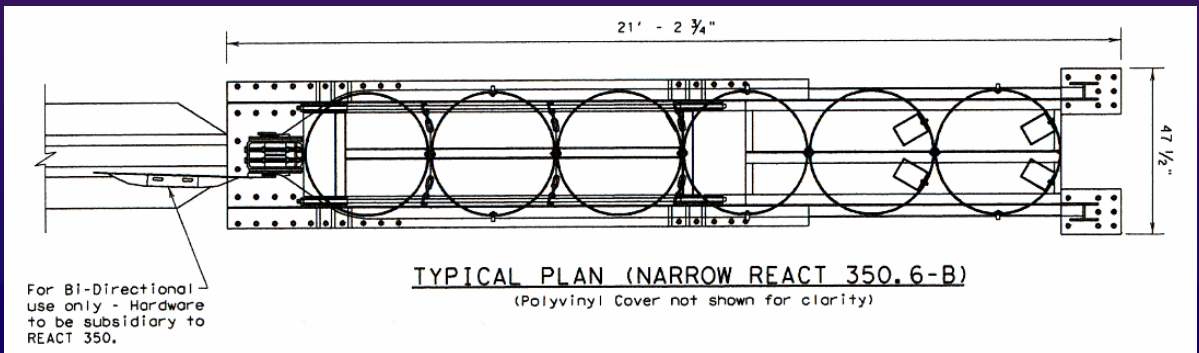
- Use re-usable high density polyethylene cylinders as energy absorbing medium
- Impacted on nose
 - System collapses & crushes HDPE cylinders (consume energy)
 - After impact:
 - *HDPE largely self-restore to original shape*
- Impacted on side
 - Redirection

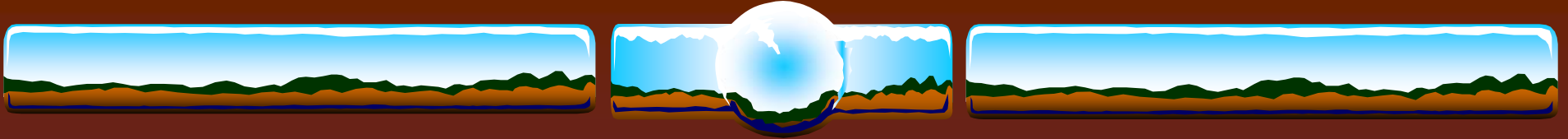




REACT Narrow

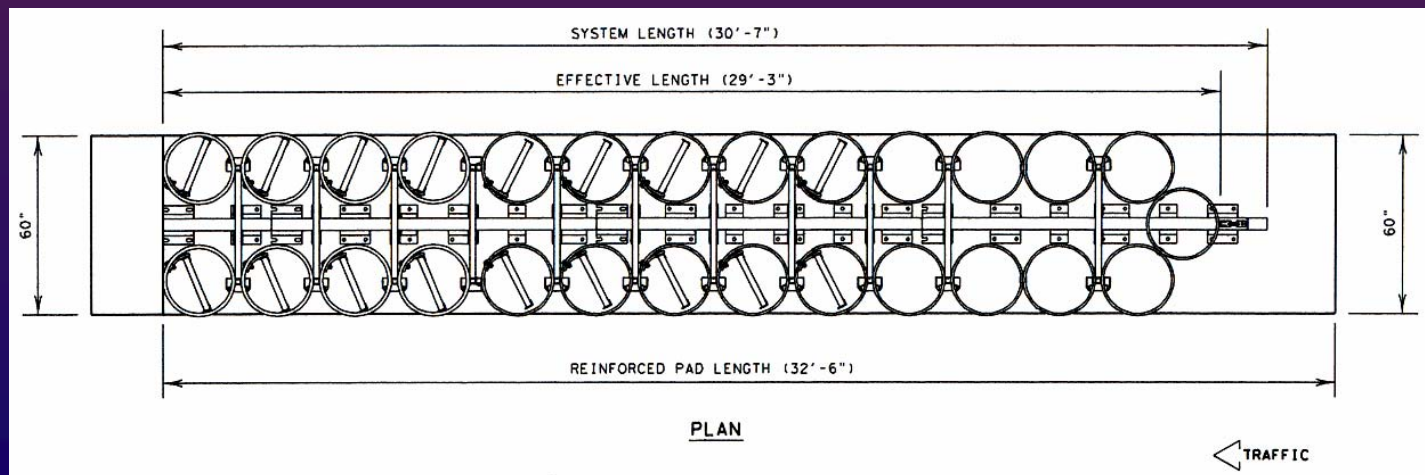
- ❑ Non-gating
- ❑ Use HDPE vertically oriented cylinders
- ❑ Steel cables on each side
 - Re-directive type impacts
 - Steel undercarriage
 - Anchorage
 - *Cylinders & cables*
 - *To the road surface*





REACT Wide

- Non-gating
- Use HDPE vertically oriented cylinders
- Parallel rows of HDPE cylinders mounted atop monorail system to protect wide objects





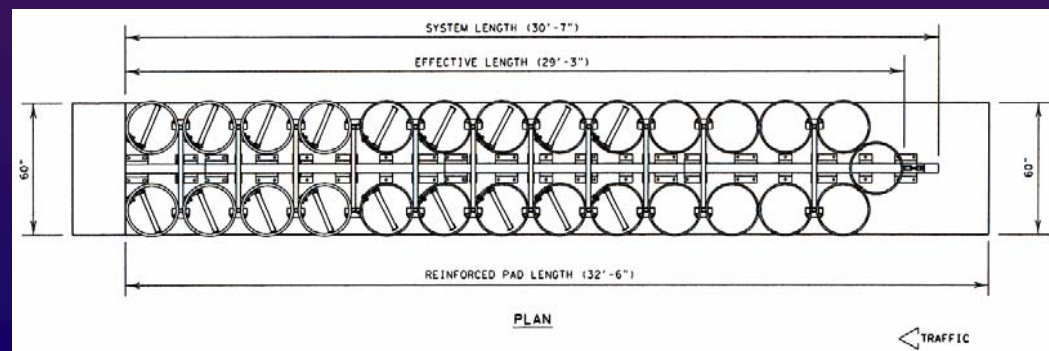
REACT Wide *(cont)*

□ Steel diaphragms

- Transmit load to base track/monorail in redirective impact

□ Steel undercarriage

- Anchorage to cylinders
- Anchorage to road surface

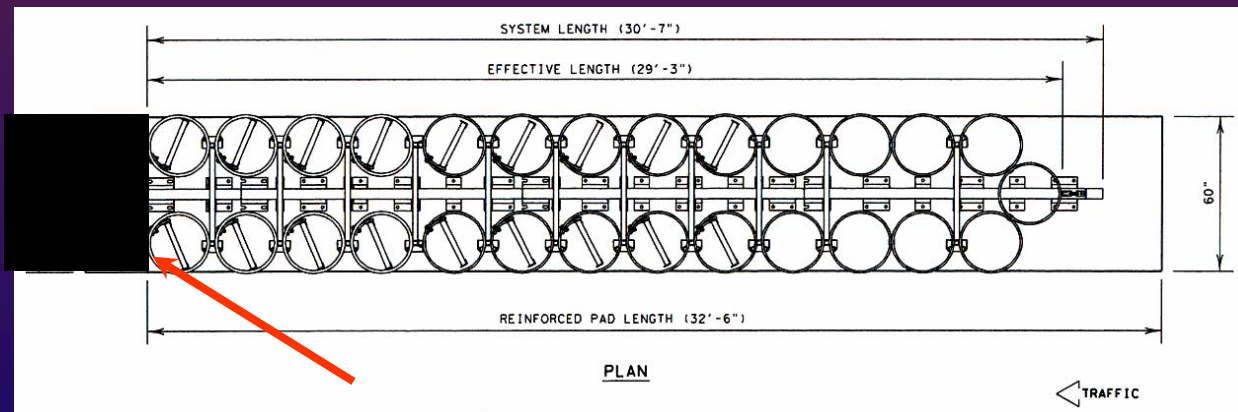


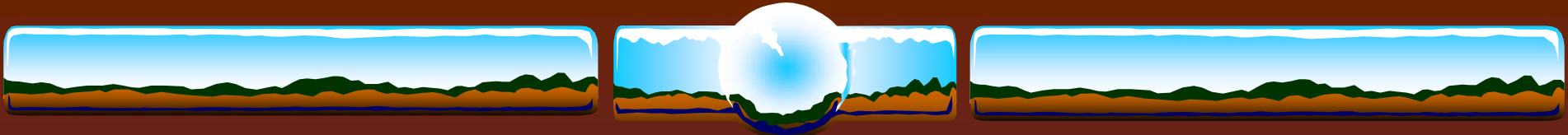


REACT Wide *(cont)*

□ FAILURE

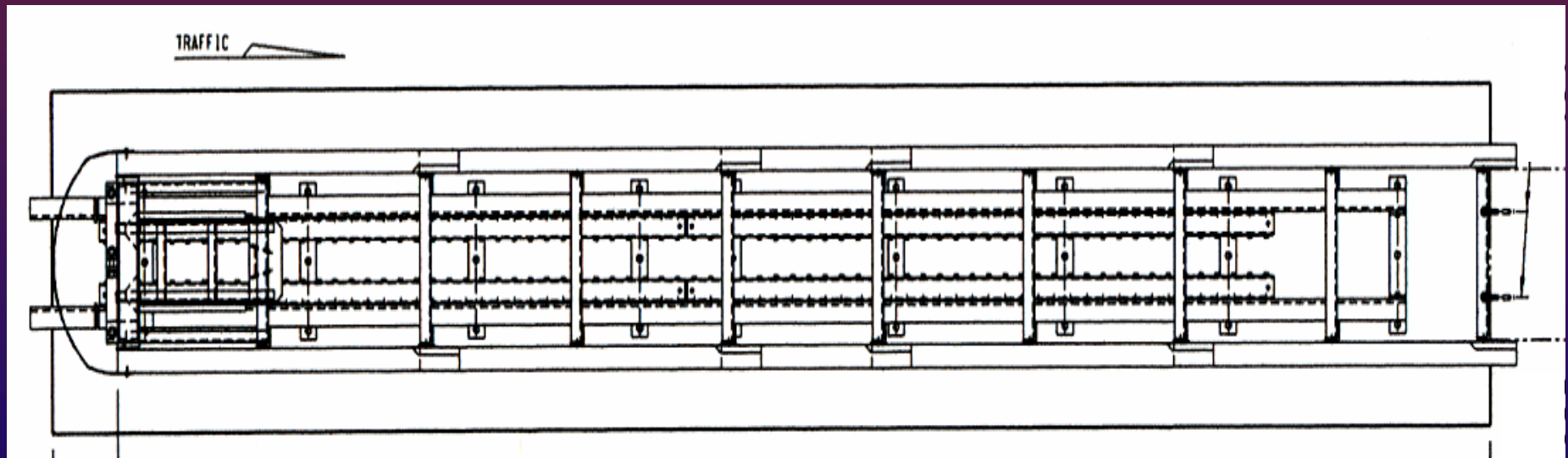
- Excessive deflections near rear of system –
Vehicle contact object shielded by the system





TRACC System

□ Redirective, non-gating



Center for
Transportation Safety
Texas Transportation Institute



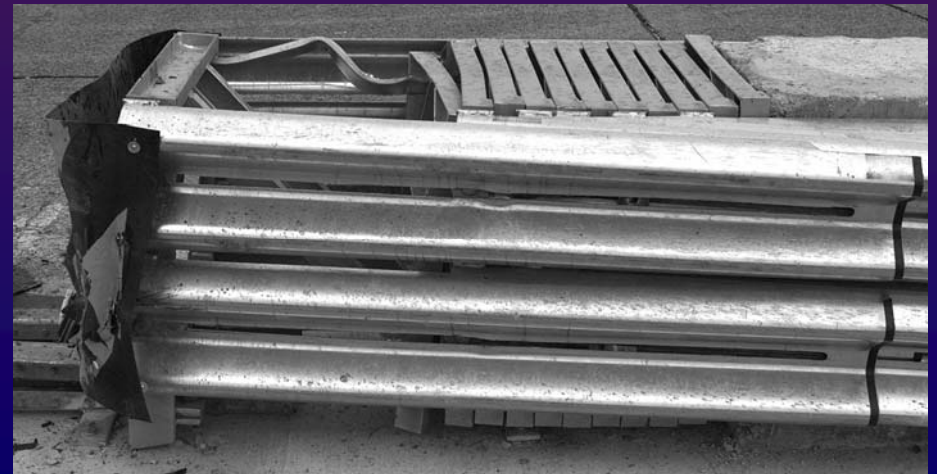
Safety and
Structural Systems

TRACC System *(cont)*

□ Impacted on the NOSE



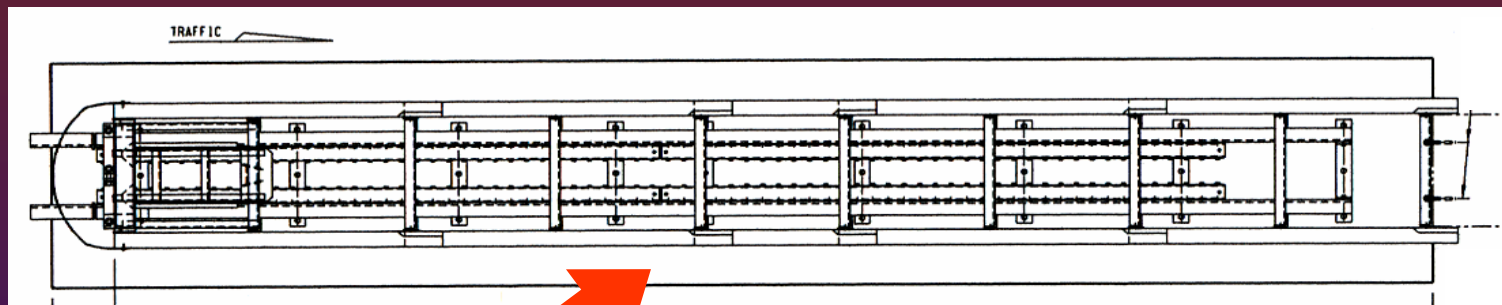
- System collapses
- Tears perforated plates within system undercarriage (consume energy)
- Amount of collapse
 - Vehicle type
 - Impact speed
 - Impact angle





TRACC System *(cont)*

□ Impacted on SIDE



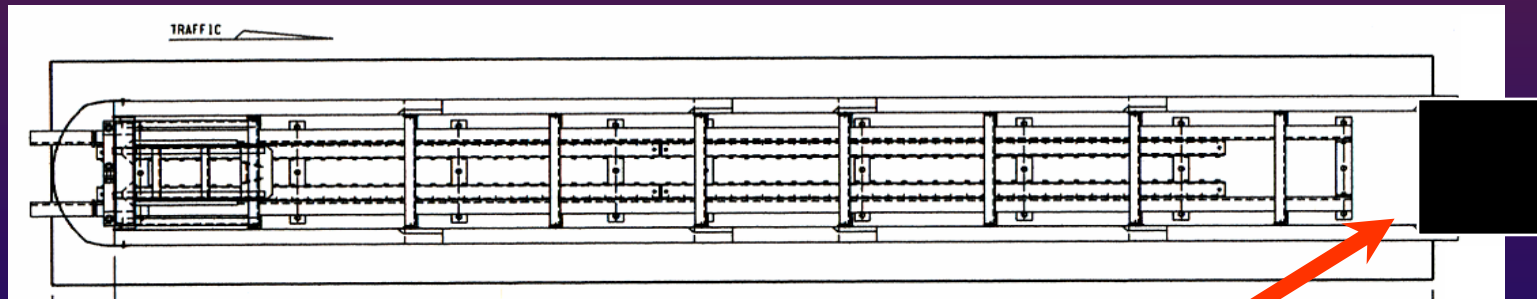
- Redirection from shielded object
 - Fender panels
 - Diaphragms
 - Undercarriage





TRACC System *(cont)*

- When TRACC doesn't perform as intended
 - Excessive deflections near rear of system
 - Vehicle made contact with the object it protected





SAND BARREL SYSTEM

- Non-redirective
- Conservation of momentum
 - Reduction of vehicle velocity when sand accelerated to velocity close to vehicle velocity
- Staging of sand
 - Staged in increased manner
 - Prevent excessive decelerations to impacting vehicle
 - And still reduces vehicle speed before it reaches the shielded object





SAND BARREL SYSTEM *(cont)*

□ FAILURE

- Excessive deflections near rear of system
 - Vehicle made contact with the object it protected
- Moisture collected in sand
 - Degrade impact performance
- Incorrect installation
 - Premature stoppage of vehicles & excessive damage





Impacted system: Performed as intended



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



TX BARREL SYSTEM

- **Non-redirective**
 - Gore areas & medians
- **55 gallon drums**
 - Varied crush strength
 - Top & bottom lid section modification
- **IMPACTED**
 - Barrels crushed
 - Impact other than nose
 - System crushes
 - Vehicle captured





TX BARREL SYSTEM *(cont)*

□ FAILURE

- Excessive deflections near rear of system
 - Vehicle made contact with the object it protected
- Not tested to current standards (NCHRP 350)
 - ? Pickups & SUV's
 - *Field experience only*





Impact on nose



Impact on other than nose



Center for
Transportation Safety
Texas Transportation Institute



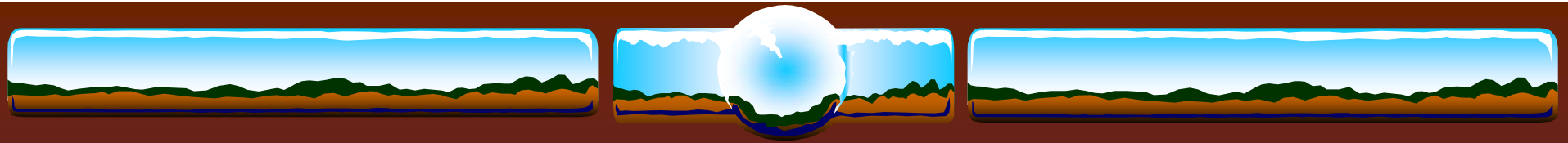
Safety and
Structural Systems



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



IMPACT ATTENUATORS

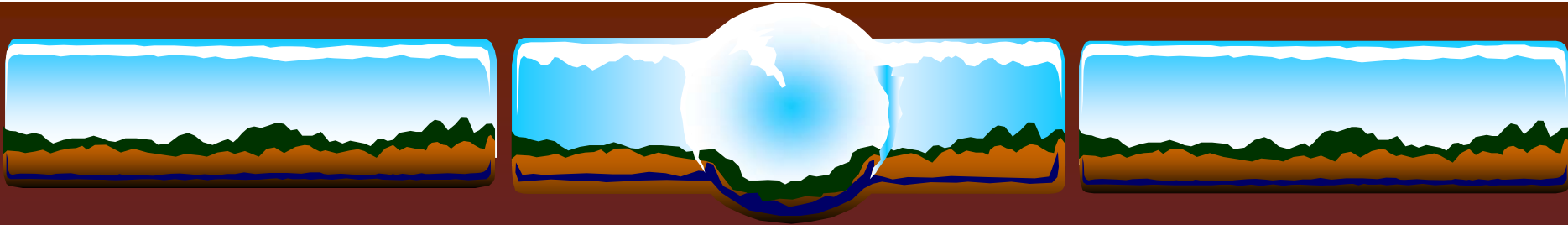
□ Questions?



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



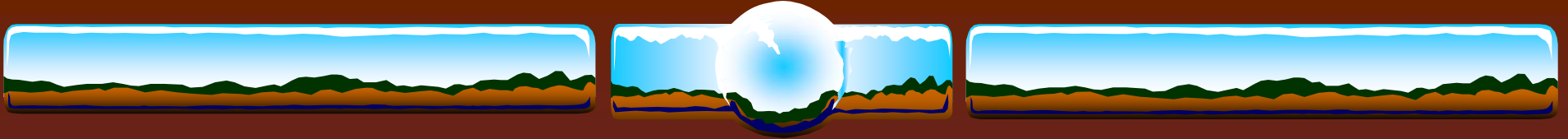
END TREATMENTS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



SINGLE GUARDRAIL TERMINALS

□ Tube height

➤ $<4''$

- Snagging vehicle undercarriage

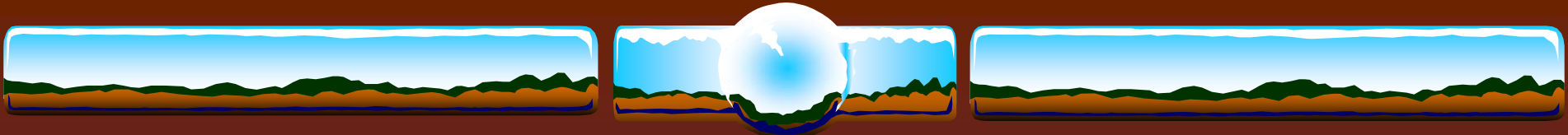
□ Graded terrain

- Vehicle pass over non-breakaway portion of installation

□ Cross-slope of surrounding terrain (10:1 preferred)

- Steeper may cause $>4''$ tube





SINGLE GUARDRAIL TERMINALS



- Installed wrong
- Too much foundation tube showing
- Ground strut should be on ground



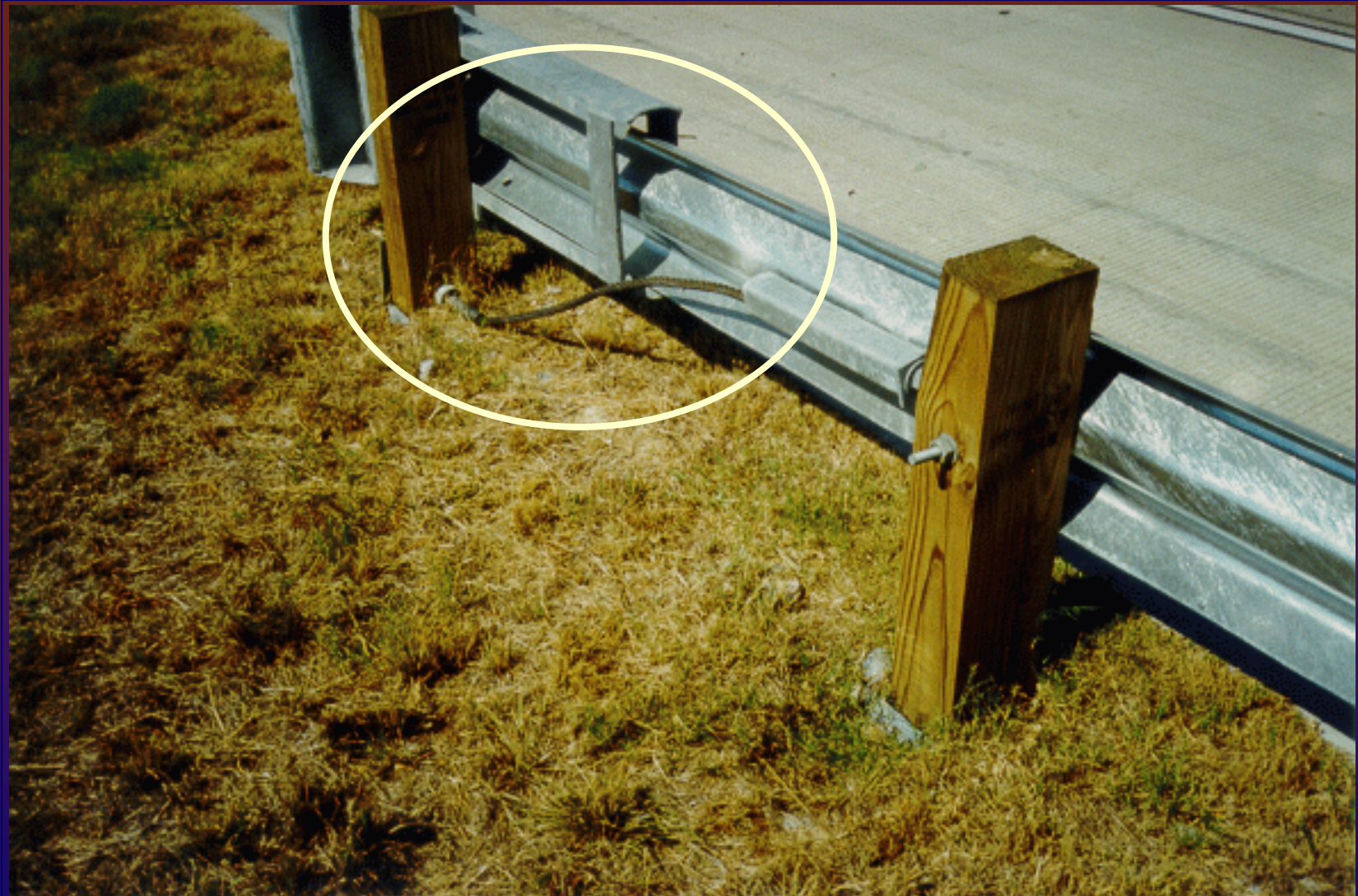


SINGLE GUARDRAIL TERMINALS



Terminal head
should be
aligned with the
guardrail system





Loose cable



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



END TREATMENTS

- ❑ Normally gating & redirective
- ❑ Failures
 - Impacts on end
 - Improper feeding of W-beam through impact head
 - Improper “gating”
 - More problematic: Smaller vehicles
 - Improper activation
 - *May cause excessive rotation on the vehicle*
 - Present side of occupant compartment
 - Guardrail deformation of the occupant compartment
 - Redirective impacts
 - Rail rupture
 - Loss of anchorage
 - And/or excessive pocketing





END TREATMENTS *(cont)*

□ Failures *(cont)*

➤ Redirective impacts *(cont)*

- Rail rupture
 - *Vehicles allowed into areas where guardrail shielded*
 - *May cause spearing on unprotected & ruptured ends*
- Loss of anchorage
 - *When: Premature release of the anchor cable on*
 - Either end
 - W-beam or
 - Post 1
 - *Vehicles allowed into areas where guardrail shielded*
 - *May cause spearing on unprotected & ruptured ends*
 - *Can cause rail element to drop*
 - Cause ramping





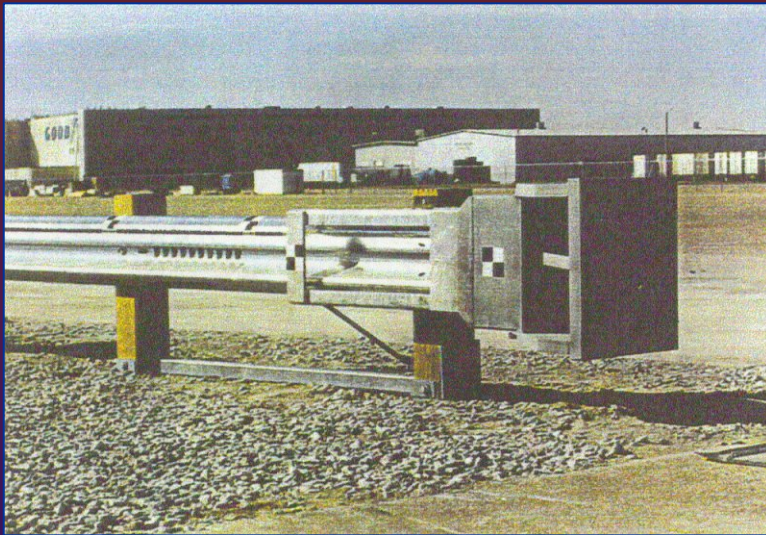
END TREATMENTS *(cont)*

□ Failures *(cont)*

- Redirective impacts *(cont)*
 - And/or excessive pocketing
 - *When*
 - Partial loss of anchorage +/-
 - Excessive post deflections
 - Breakage
 - *Cause*
 - Excessive roll
 - Pitch angles
 - May result in rail rupture



BEST



http://www.modot.state.mo.us/design/end_terminal/images/best1.jpg



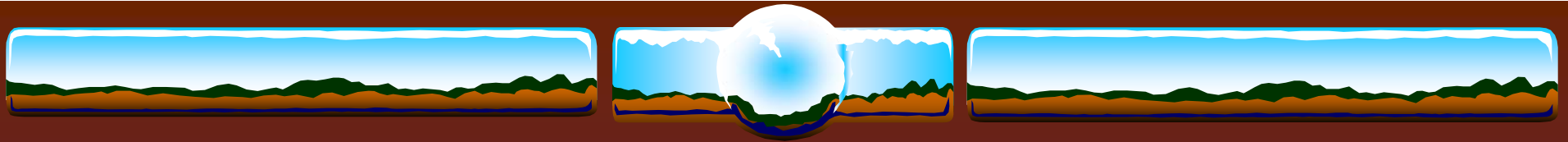
www.unl.edu/matc/best.jpg



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



BEST *(cont)*

- **HIT “END-ON” (@ 0 degrees)**
 - W-beam feeds through impactor head
 - Cuts W-beam in 4 plate sections
 - Deflects away from vehicle
- **HIT @ larger angles near nose of device**
 - End of system “gates”
 - Allows vehicle to pass through the end section
- **Breakaway posts in terminal & fracture/release when impacted in weak axis**





BEST *(cont)*

□ Vehicle redirection

- IF System impacted
 - @ post 2
 - < 25 degree impact angle
 - < 60 mph
 - Vehicle \leq $\frac{3}{4}$ pickup



ET 2000 (&+)

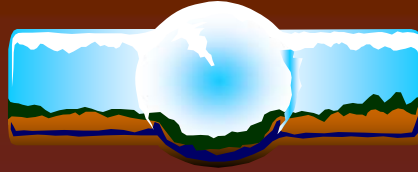
□ Impact “end-on”

- @ 0 degrees
 - Flattens & deflects w-beam guardrail
- @ greater angles near nose
 - End of system “gates”
 - Vehicle pass through the end section
- Impact on post 2 or beyond
 - Redirection if
 - $\leq \frac{3}{4}$ pickup
 - < 25 degrees
 - < 60 mph



http://www.modot.state.mo.us/design/end_terminal/images/et_2000_extruder.jpg





Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems

ET 2000 (&+) *(cont)*



Center for
Transportation Safety
Texas Transportation Institute

&

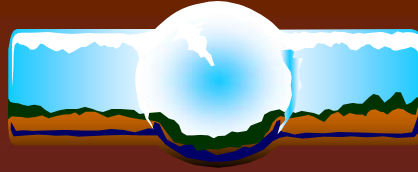
Safety and
Structural Systems

ET 2000 (&+) *(cont)*

□ Example:

- High angle impact
- Terminal gated
- Note wheeltracks
- Little fed through, but still OK





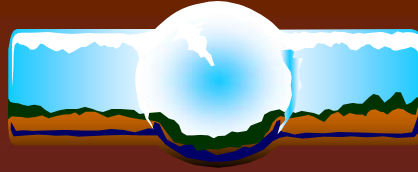
Pavement overlays...!



Center for
Transportation Safety
Texas Transportation Institute

&

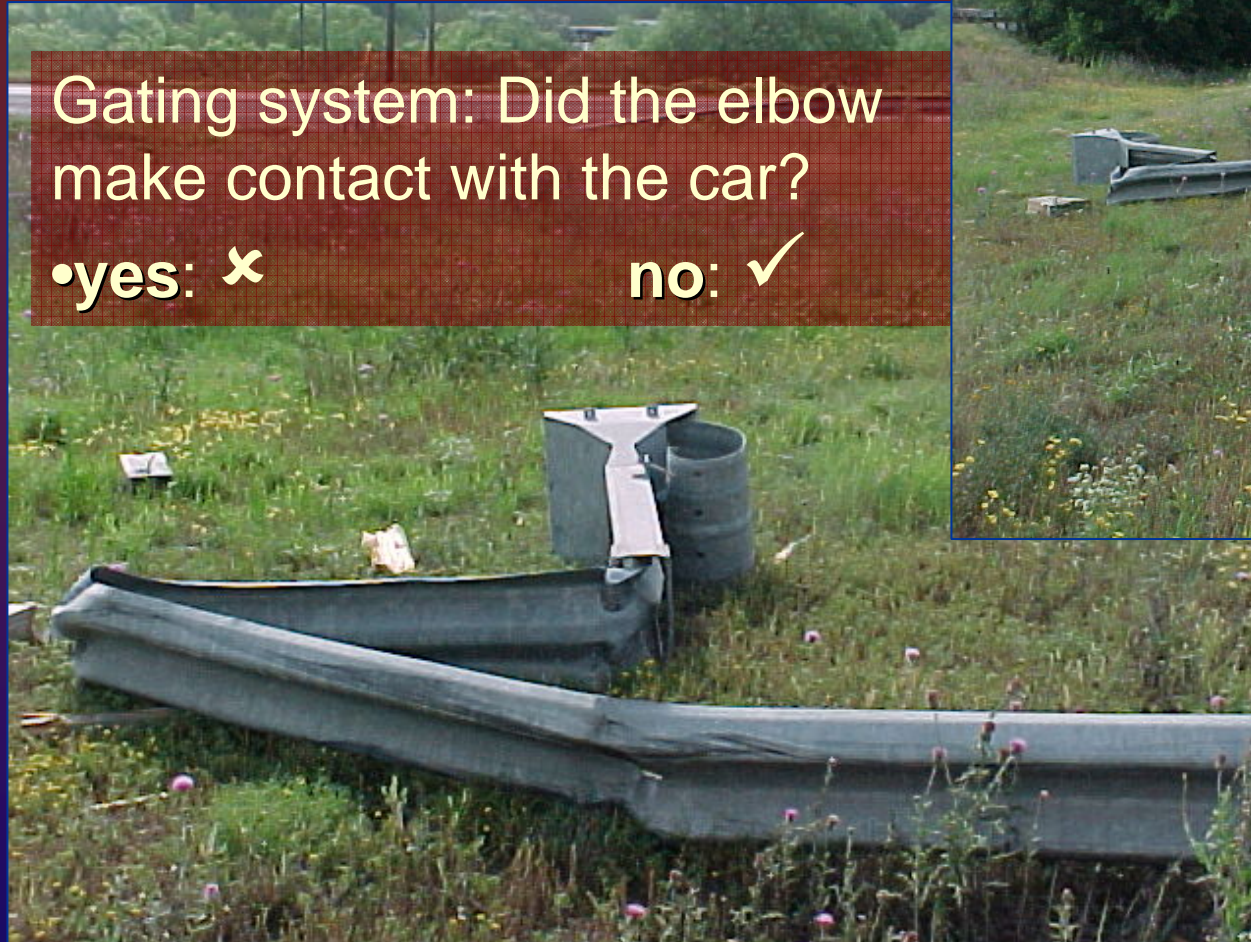
Safety and
Structural Systems



Gating system: Did the elbow make contact with the car?

•yes: ✘

no: ✔



Center for
Transportation Safety
Texas Transportation Institute



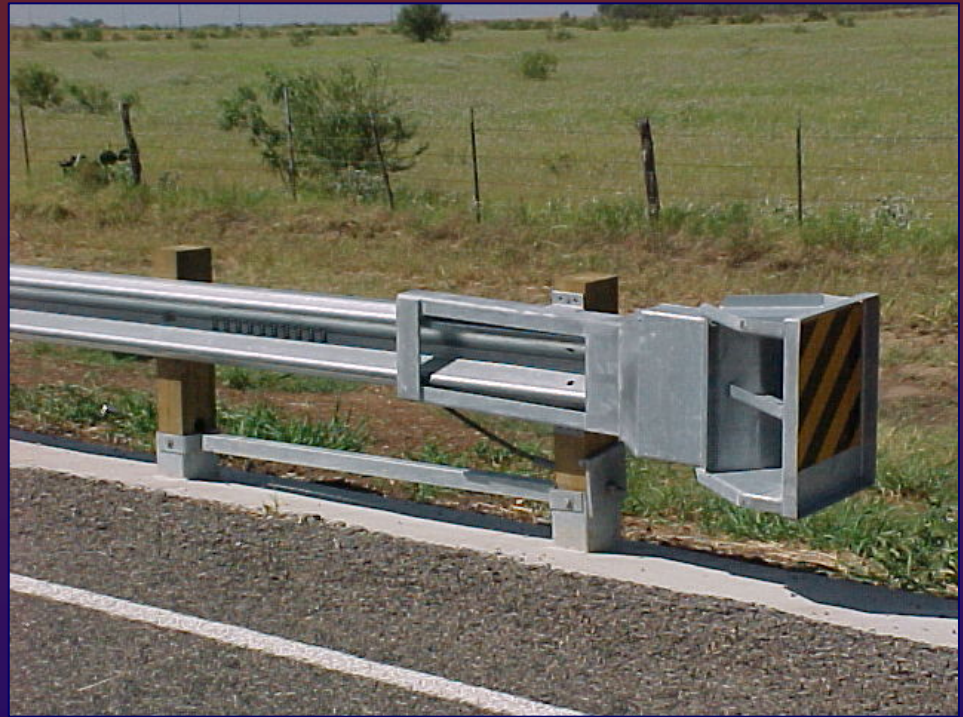
Safety and
Structural Systems



SKT

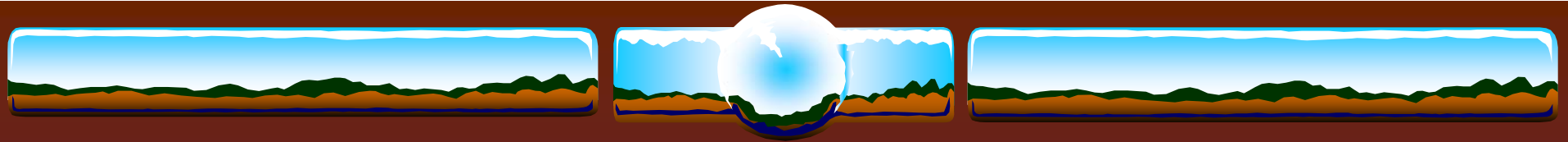
□ Hit “end-on” @ 0 degrees

- Deflects W-beam guardrail
- Fed through impactor head
- W-beam contacts deflector plate
 - Short sections of W-beam curved away from impactor head in “kinked” fashion



Installed wrong





SKT *(cont)*

□ Impacted @ greater angles near nose

- End of system “gates”
- Vehicle pass through the end section
- Breakaway posts
 - Incorporated into terminal
 - Fracture/ release when impacted in weak axis

□ Impact on post 2 or beyond

- Redirection if
 - $\leq \frac{3}{4}$ pickup
 - < 25 degrees
 - < 60 mph





TURNED DOWN TERMINAL

- Initially envisioned as improvement on blunt guardrail ends
 - Blunt end
 - So what does blunt ends do?
 -



High volume road ?





Blunt end of a guardrail
(a crash in South Africa where the
end-wings are still utilized)



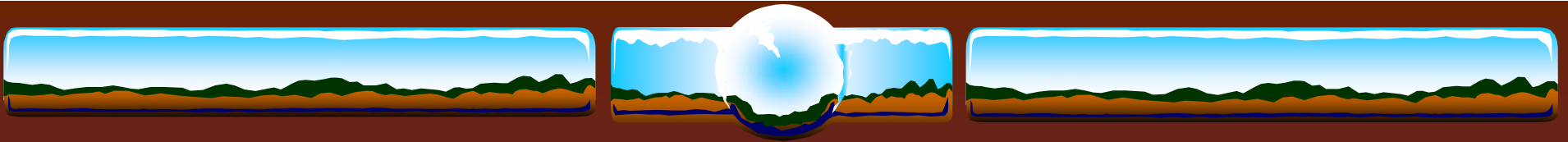
Courtesy: South African Police Service, Port Elizabeth, South Africa



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



TURNED DOWN TERMINAL *(cont)*

- 25' guardrail section, twisted down to ground level & attached to concrete block for anchorage
 - Anchorage provides tension to guardrail system
- Use
 - Downstream ends of one-way facilities
 - When OUTSIDE clear zone: 2 way facilities
- Why other systems?
 - Experience: vehicle ramping &/rollover



TURNED DOWN TERMINAL *(cont)*



Hit in length of need
(redirection only)



Vehicle got on system





END TREATMENTS

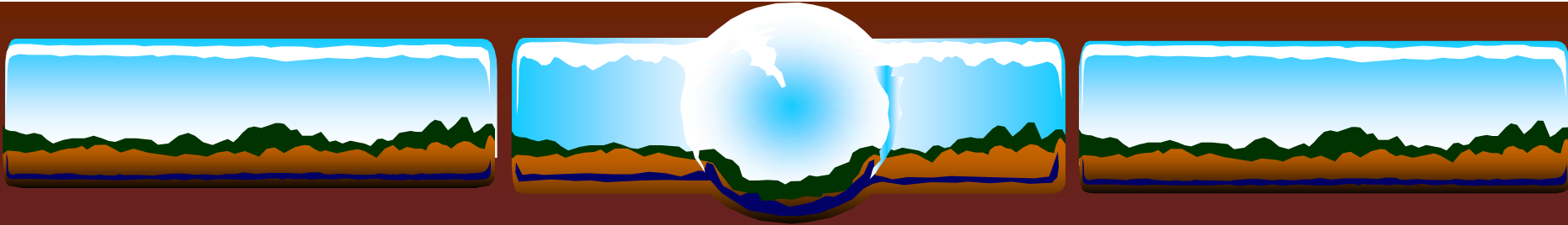
□ Questions?



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



SIGNS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems

2. SELECT THE TYPE OF DEVICE:

Sign size: < 16 ft²
 16 ft²
 > 16 ft²

Number of supports:

Number of impacted supports:

Support type: FIBER-GLASS
 U-CHANNEL
 STRUCTURAL SHAPES
 STEEL PIPE: SCHEDULE 10
 STEEL PIPE: SCHEDULE 80

OTHER:

Base type: TRIANGULAR SLIP
 SOCKET SYSTEM
 RECTANGULAR SLIP



3. DETAIL OF SYSTEM AND DAMAGE

1. Post type:

U-CHANNEL
I-BEAM
FIBER-GLASS

STEEL PIPE: SCHEDULE 10
STEEL PIPE: SCHEDULE 80
STRUCTURAL SHAPES

OTHER:

2. Base type:

TRIANGULAR SLIP
SOCKET SYSTEM

RECTANGULAR SLIP

3. What is the stub height?

inches

4. Did it break away as intended?

YES

NO

5. If it did break away: did the support bend?

YES

NO

6. Did the slip-base slip activate?

YES

NO

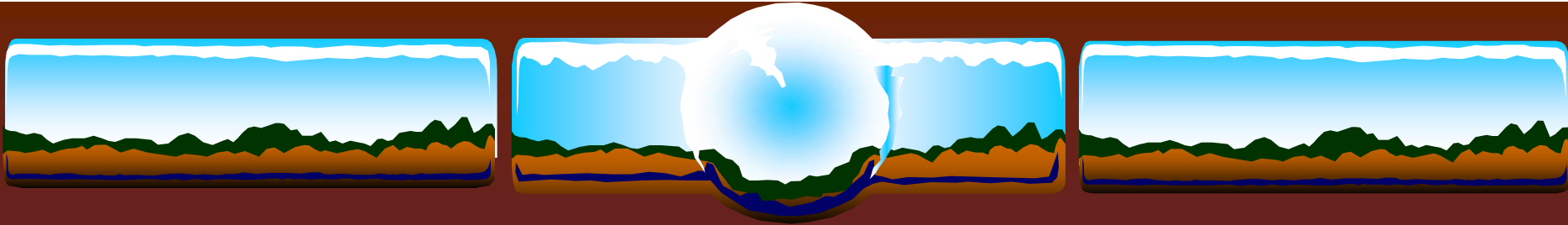
7. If it did not break away: did any of the following occur?

THE SUPPORT RUPTURED

THE SUPPORT PULLED OUT OF THE SOCKET

THE FUSE PLATE RUPTURED





SMALL SIGNS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems

SMALL SIGNS

□ How they work

- Breakaway
- Uncoupling – Slip plane
- Yielding – Permit failure of support material/ material connected with

□ Uni or multi-directional

□ Sign installation yield

- ≥ 35 mph
- Impact angle:
 - Uni-directional: 0 – 20 degrees
 - Multi-directional: Not sensitive to impact angle



Still a small sign!





SMALL SIGNS *(cont)*

□ Critical issues

- ≥ 4 " stub height
- Breakaway supports in multiple support sign structures
- Rigidity for multi-post supports to activate breakaway device
- Orientation: Ensure acceptable dynamic performance





SMALL SIGNS *(cont)*

□ Types

- Universal anchor system – Type A (fiber-glass)/ thin tube
- TX universal triangular slip base
- Perforated square metal tubing (drivable) – Type U
- Wedge anchor thin wall (drivable) – Type A





Universal Anchor System

– Type A (fiber-glass) / thin tube (cont)

□ When hit

➤ Yield to vehicle

- Either pulling out of ground anchor tube
- Fracturing tube support near top of ground OR
- Collapsing tube cross section
- Displaced from soil





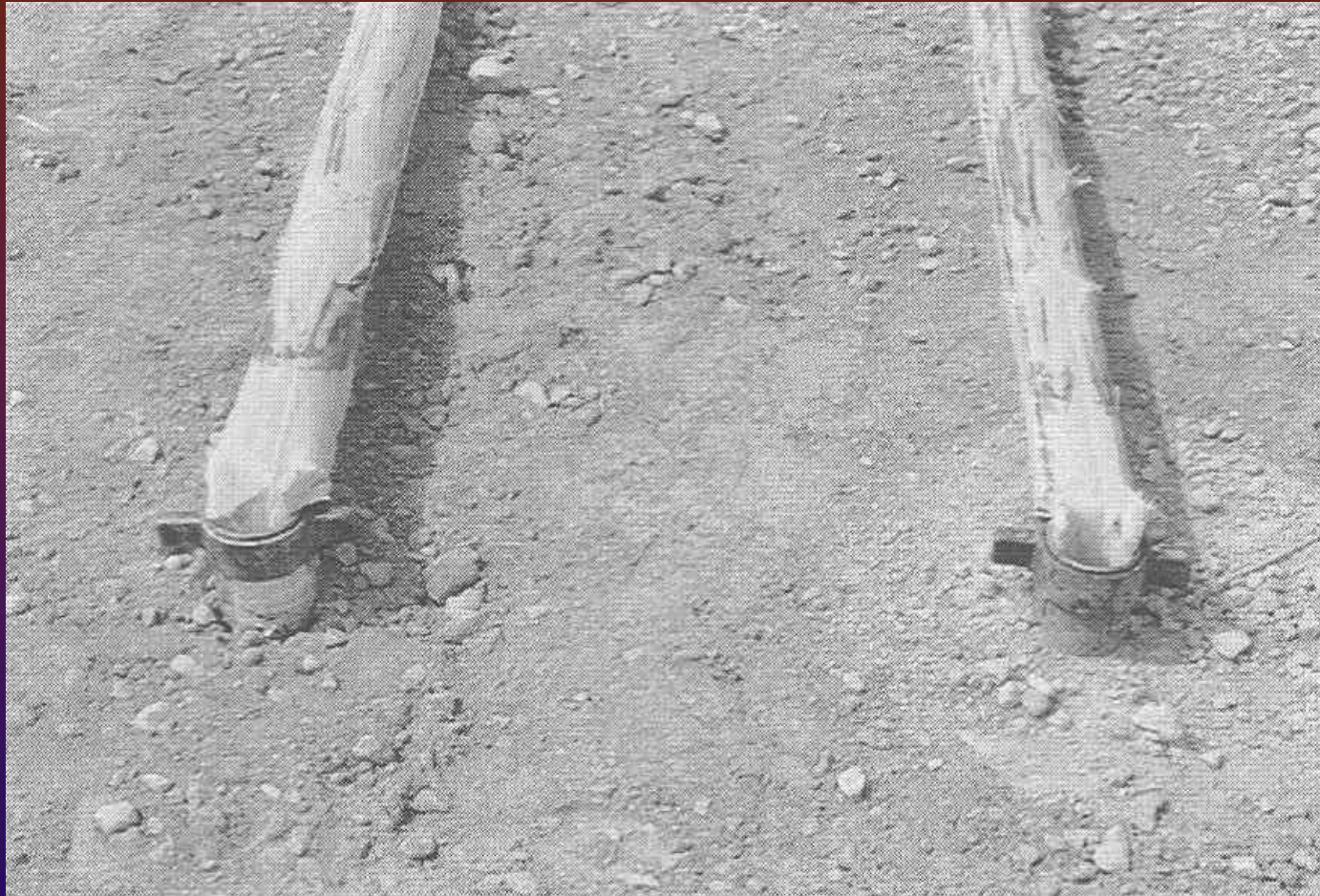
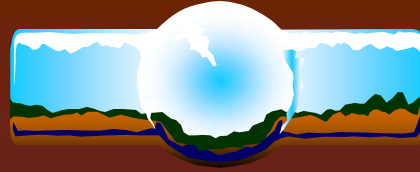
Universal Anchor System

– Type A (fiber-glass) / thin tube (cont)

❑ Improper impact performance

- Sign support failing to yield
- Yield in such a manner: Support/ sign panel penetrate into occupant compartment from any surface of the vehicle
- Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil



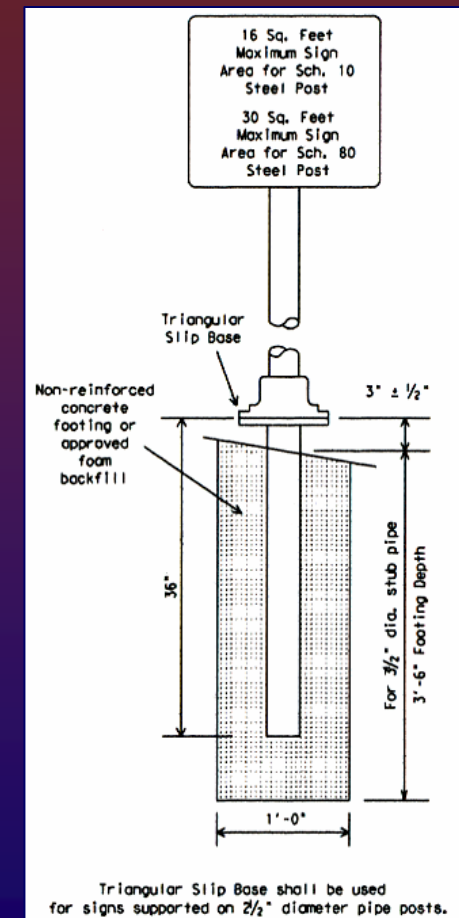
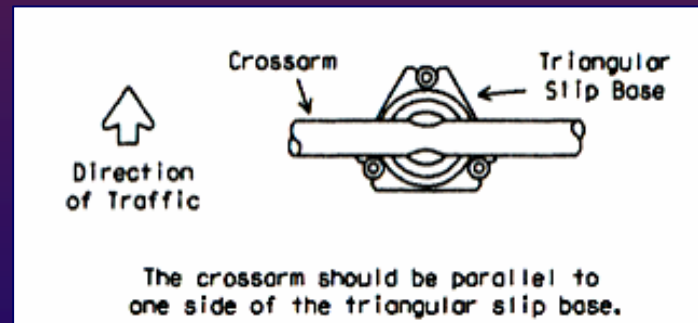


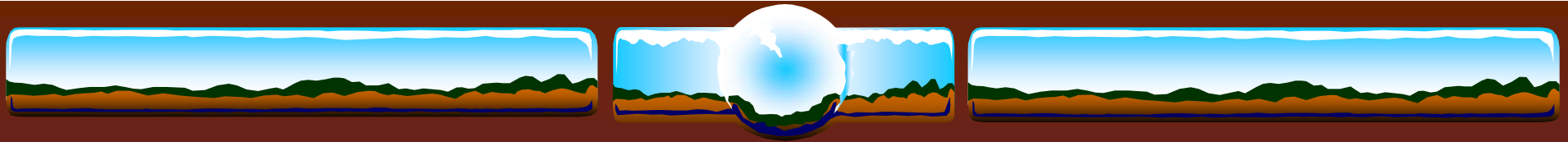
Triangular slip base with spacer on right



TX Universal Triangular Slip Base

- 3 bolts clamp individual slip base components together





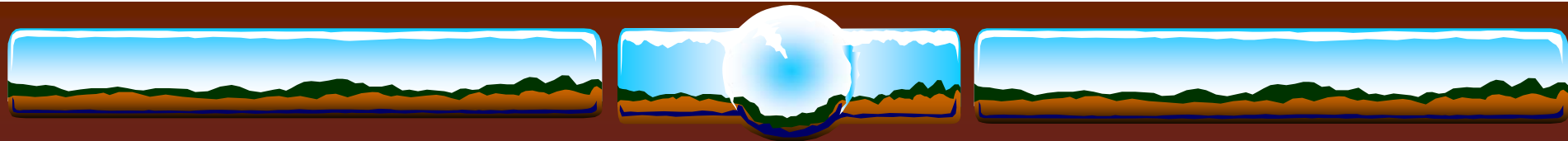
TX Universal Triangular Slip Base

(cont)

□ When hit

- Bolts forced out of slots in base
- Support(s) yield to vehicle
 - By allowing top support to release from stub post by
 - *Pushing out 3 bolts clamping upper & lower section together*
 - *Thus: releasing slip base*
- Schedule 10: Field experience
 - May bend over rather than release from slip base
 - *Not a hazard to motorist*
 - *BUT need to be noted during inspection*





TX Universal Triangular Slip Base

(cont)

❑ Improper impact performance

- Sign support failing to yield
- Sign support yielding in such a manner
 - Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
 - Slip base support not separate from slip base stub post – “locked up” = FAILURE
 - *Proper hardware during installation?*
 - *Assembly torque during installation?*
- Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil



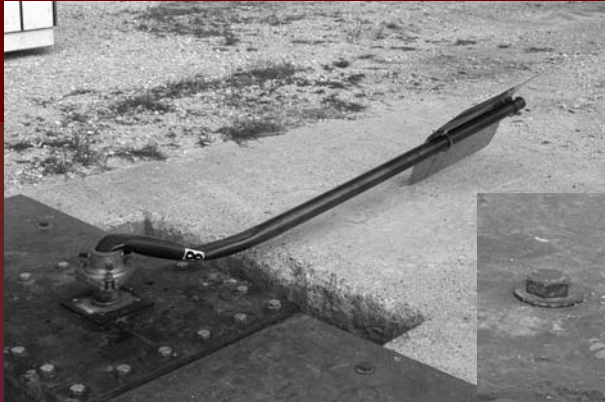


Triangular slip base on
Schedule 80



Triangular slip base





Slip base &
schedule 10



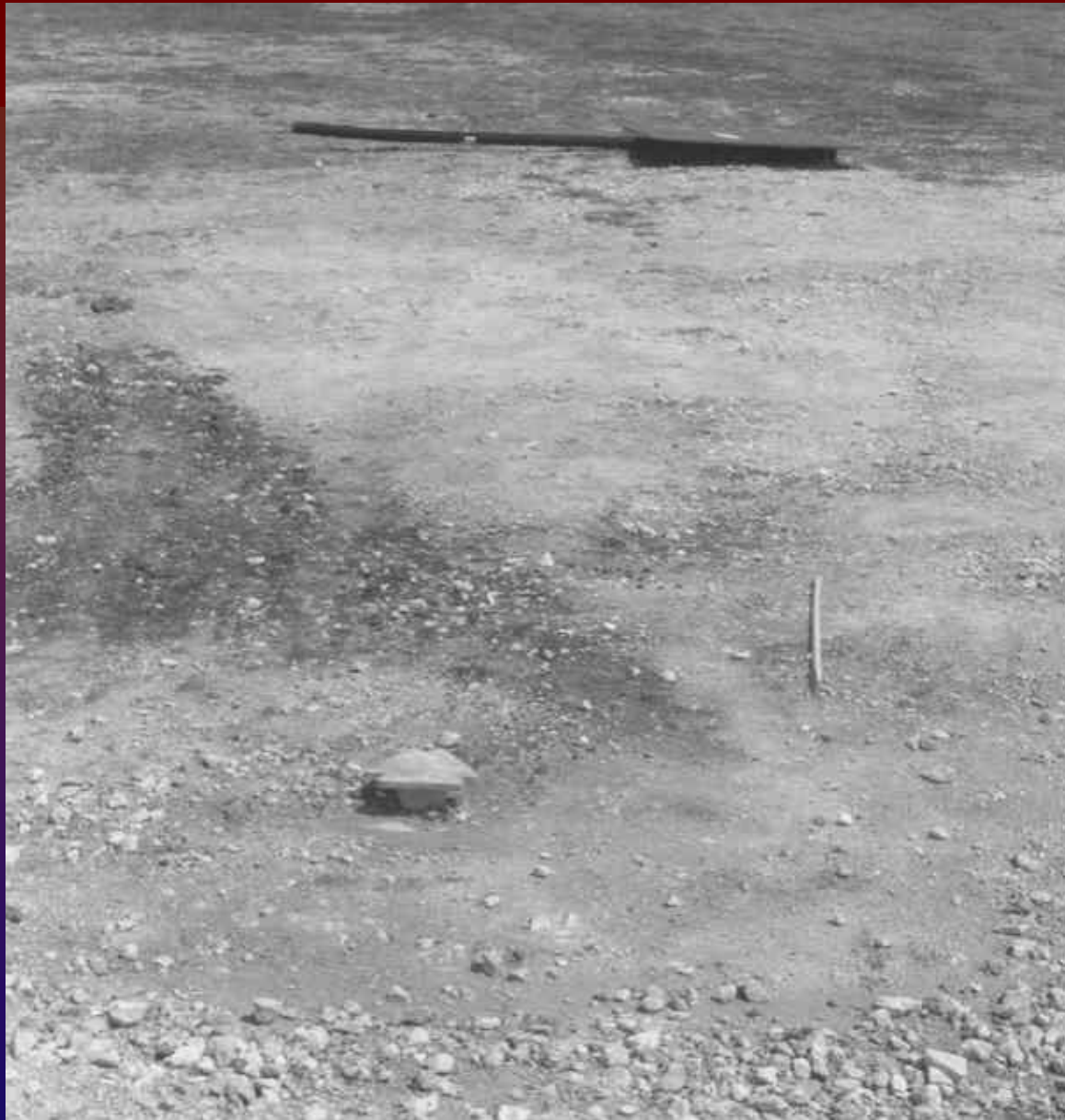
Slip base did not activate –
Did not perform as intended



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



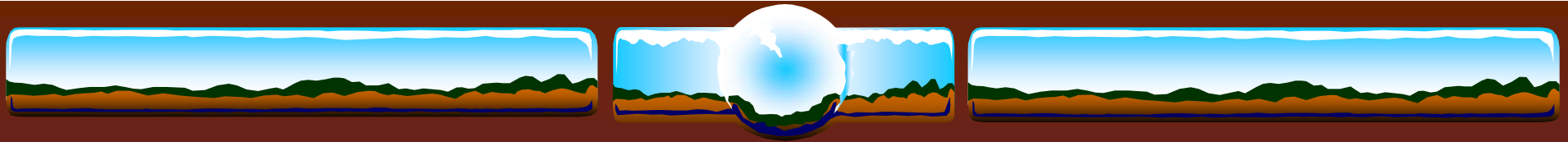
Slipbase activated



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



Perforated Square Metal Tubing

(drivable) – Type U

- Proprietary corner bolt & flanged washer nut secure support to ground anchor stub

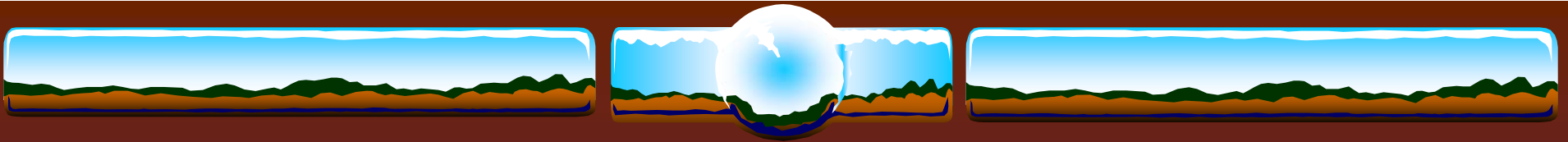
- When hit
 - Support(s) yield to vehicle
 - Top support release from ground stub by
 - *Fracturing cross-section of support @ or near top of ground & laying over*



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



Perforated Square Metal Tubing

(drivable) – Type U (cont)

❑ Improper impact performance

- Sign support failing to yield
- Sign support yielding in such a manner
 - Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
- Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil





U-channel

- Lap-splice connection
- Fractured @ bumper height
- Base activated
- “Marginal” performance



U-channel
Back to back = Undesirable
Directly buried = Not TXDOT practice



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



U-channel lap
splice -
INCORRECTLY
installed



Center for
Transportation Safety
Texas Transportation Institute



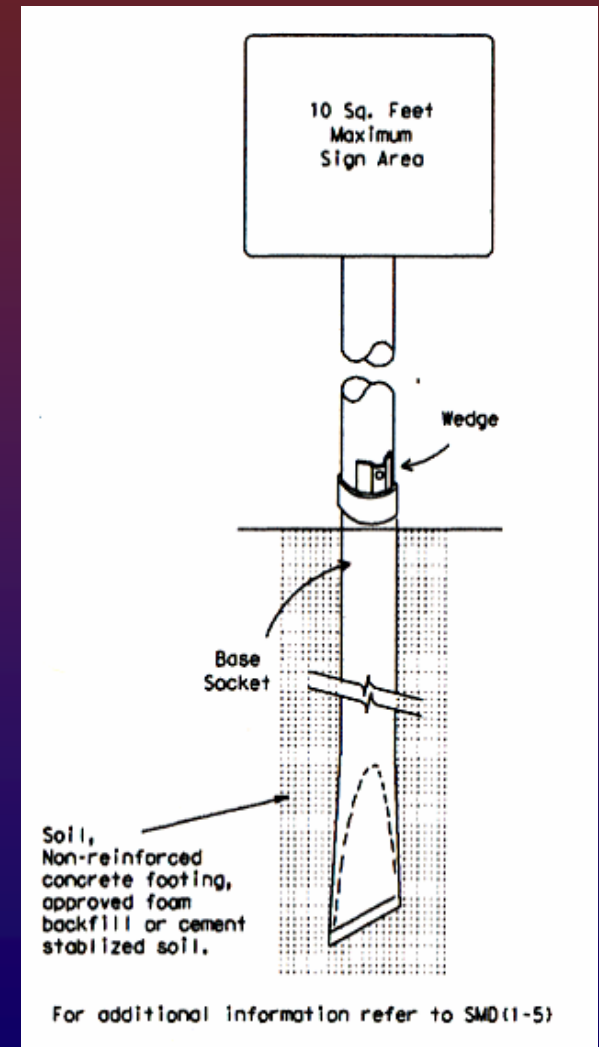
Safety and
Structural Systems

Wedge Anchor Thin Wall

(drivable) – Type A

- ❑ Sign max 10 ft²
- ❑ When hit
 - Yield to vehicle by
 - Allow top support to release from ground stub by
 - *Pulling out of ground anchor tube*
 - *Collapsing tube cross section*

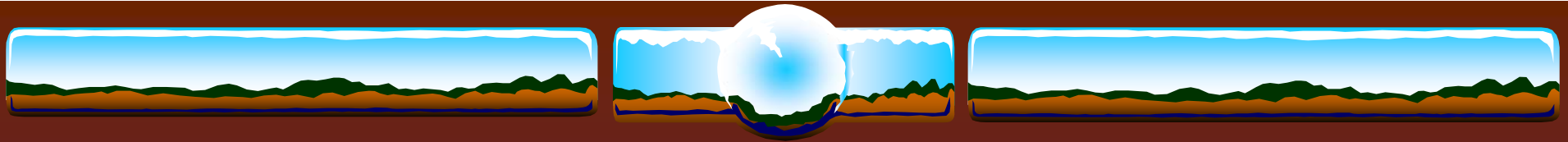
❑ Improper impact performance



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



Wedge Anchor Thin Wall

(drivable) – Type A (cont)

❑ Improper impact performance

- Sign support failing to yield
- Sign support yielding in such a manner
 - Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
- Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil





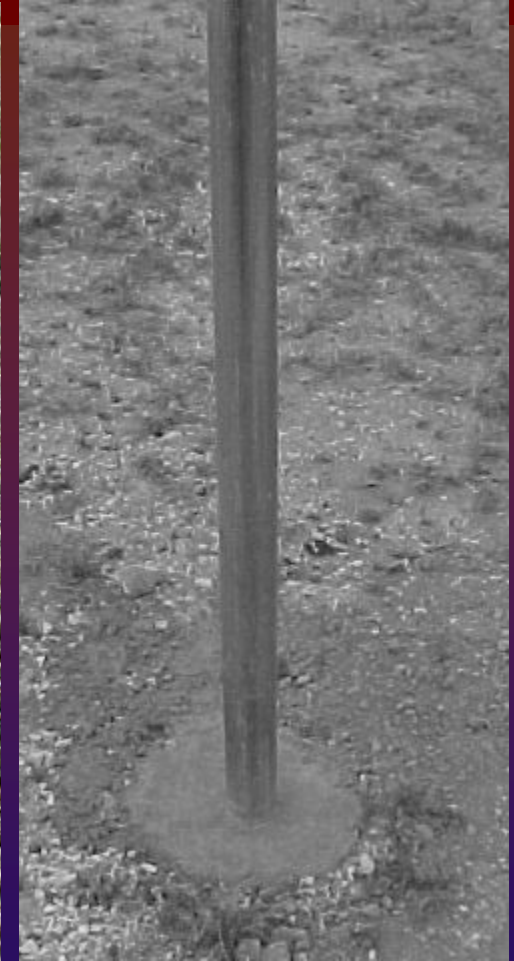
! Why isn't this sign post falling over?



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



TxDOT did away with all buried supports



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



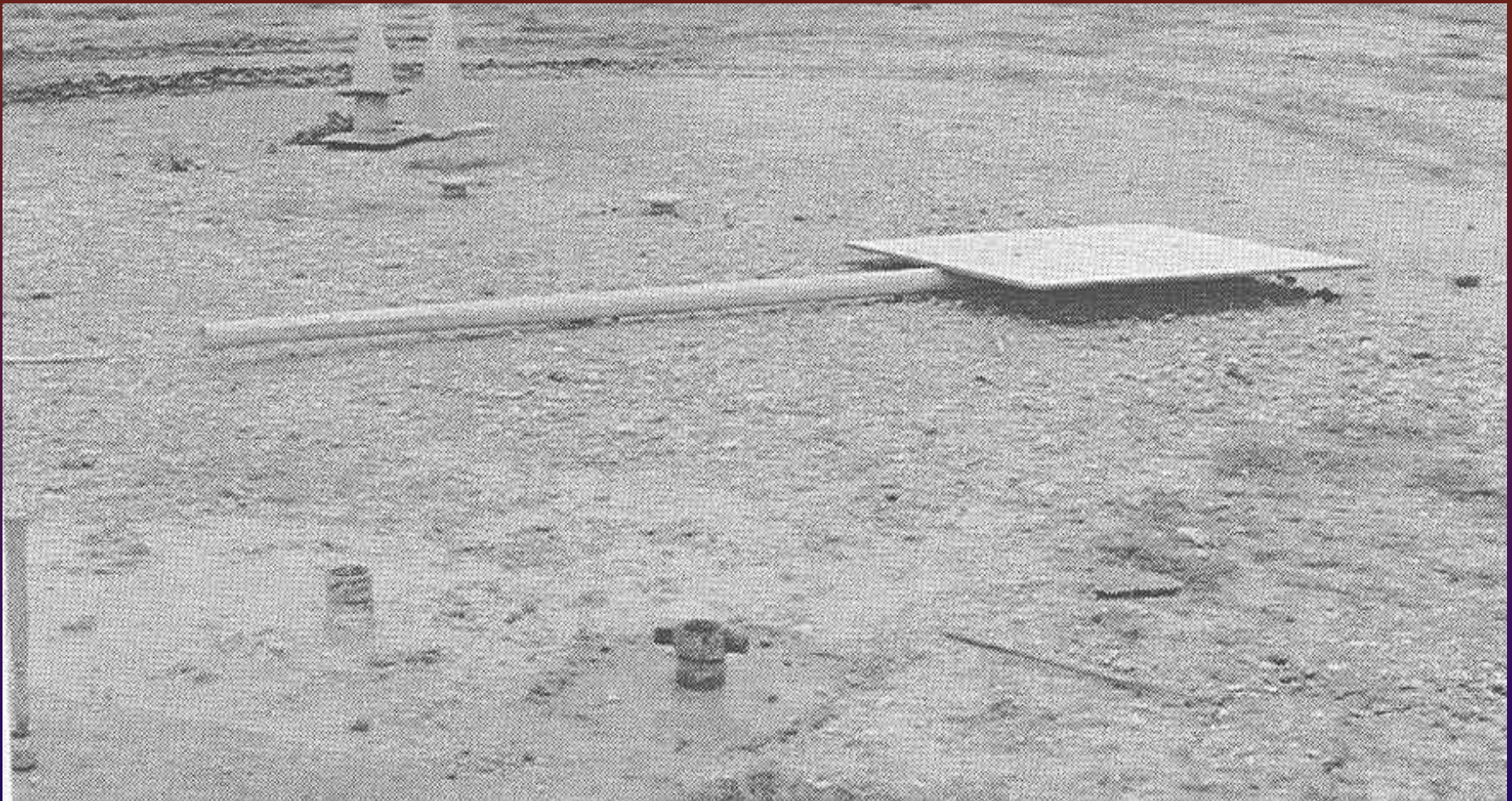
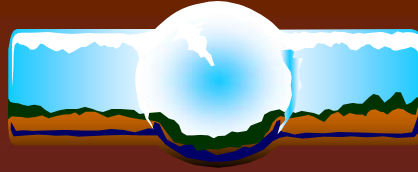
Post pulled from ground stub – GOOD performance



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



Stub height



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



Is this welded?
“... plumbing”



Is the wedge type
full of water or
debris?



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems

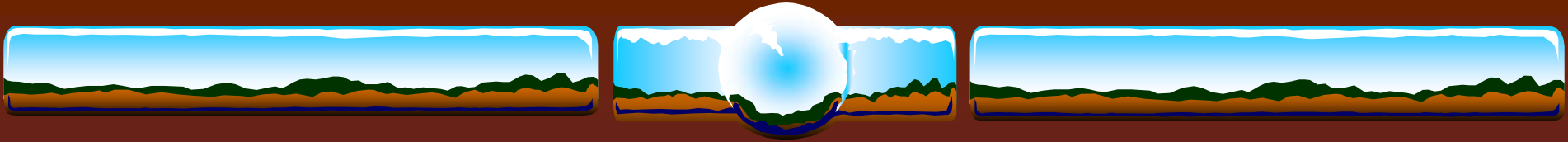


Stub too high



Socket system – Did not activate
will fall over





SMALL SIGNS

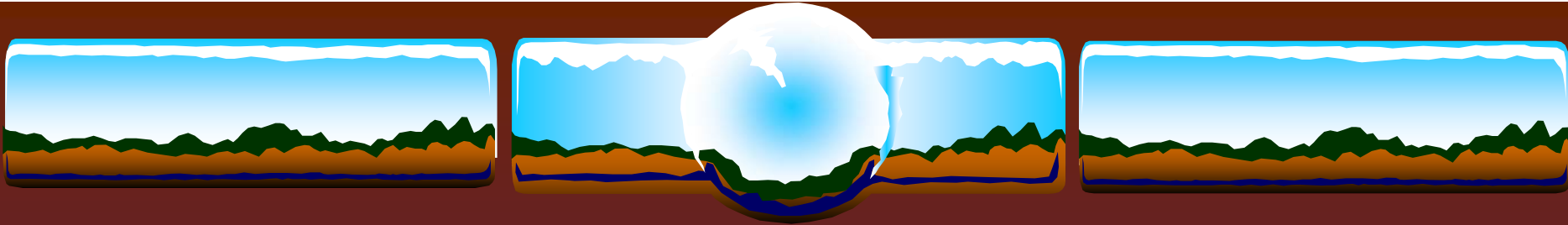
□ Questions?



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



LARGE SIGNS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



LARGE SIGNS

□ How they work

- Give way to errant vehicle impacting the system
 - Uncoupling: through slip plane (slip base) near ground level
 - Permitting material failure of perforated hinge fuse plate
 - *Connecting: Upper and lower supports together*
 - Due to mass of large support size
 - *Support member hinge fuse plate mechanism near base of sign panel is necessary*
- When impacted at
 - ≥ 35 mph &
 - Impact angle: 0-25 degrees





LARGE SIGNS

□ Critical elements

- Substantial remains of breakaway supports <4”
- Multipost breakaway sign supports
 - Hinge: > 84” above ground level
 - *No portion of sign/ upper section of support likely to penetrate windshield of impacting car/ medium- sized truck*
 - Single post spaced with clear distance 84” or more from another post
 - *Mass ≤ 44 lb/ft*
 - *Total mass below hinge but above shear plate of breakaway base: ≤ 600 lb*
 - No supplemental sign attached below hinges – If interfere with breakaway action of support post / penetrate windshield





LARGE SIGNS

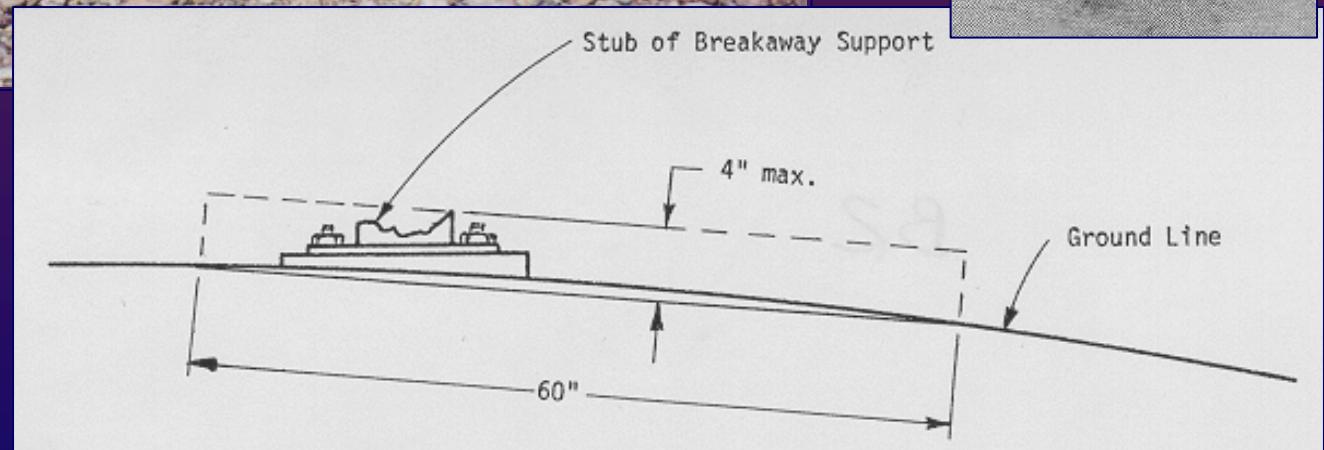
□ Critical elements (*cont*)

- Multipost breakaway sign supports (*cont*)
 - Each support consider acting together UNLESS
 - *Sign supports designed to independently release from sign panel +*
 - *Sign panel has sufficient torsional strength to ensure this release +*
 - *Clear distance between supports = >84"*
 - Sufficient strength in connections between post & sign to allow hinge system to function on impact
- Slip base breakaway device: Oriented in direction that ensures acceptable dynamic performance





Stub height



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



3-BOLT SLIP BASE

□ How they work

- Bolts forced out of slots in the base
- Perforated hinge fuse plate fails on impacted side of support
- Bends/ fractures at opposite flange
- Permits the support to separate from the sign panel
- Normally: Sign installation remains upright & intact
 - Only bolts, keeper plate & fuse plate needs replacement

□ When they don't perform as intended

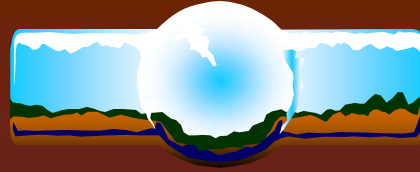




3-BOLT SLIP BASE *(cont)*

- **When they don't perform as intended**
 - Sign support failing to yield
 - Yield in such a manner: Support/sign panel penetrate into occupant compartment from any surface of the vehicle
 - Slip base support don't separate from slip base stub post = locked up
 - Proper hardware?
 - Assembly torque during installation?
 - Fuse plate: if not activate – Compare with TXDOT std drawings
 - Ground stub and/or foundation should NOT
 - Pulled OR
 - Displaced from soil





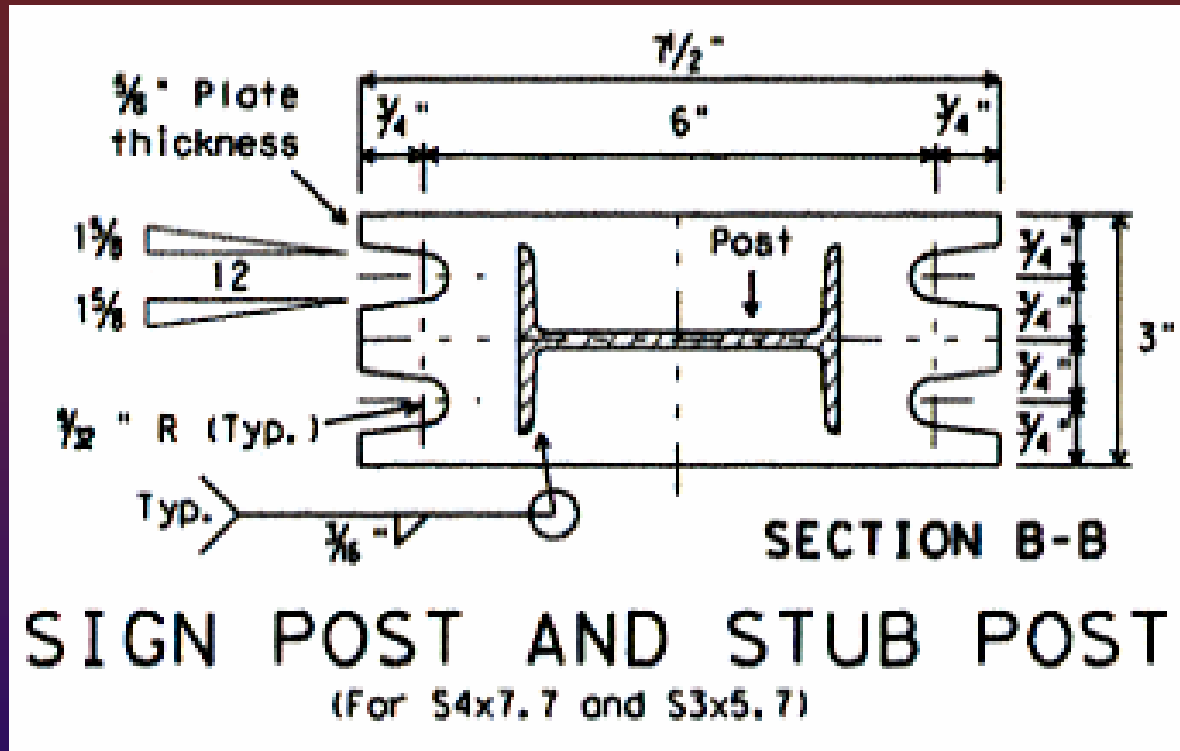
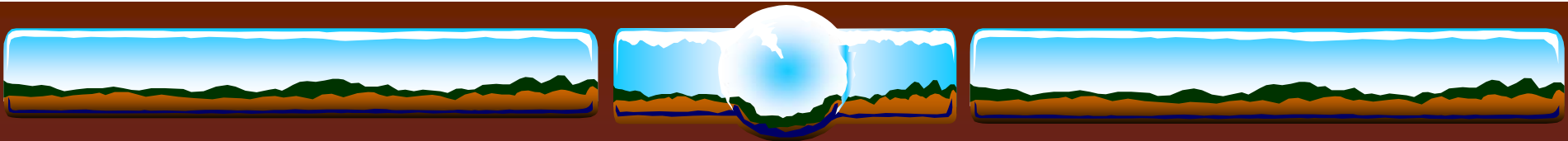
Post on left buried – Will not perform as intended!



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems





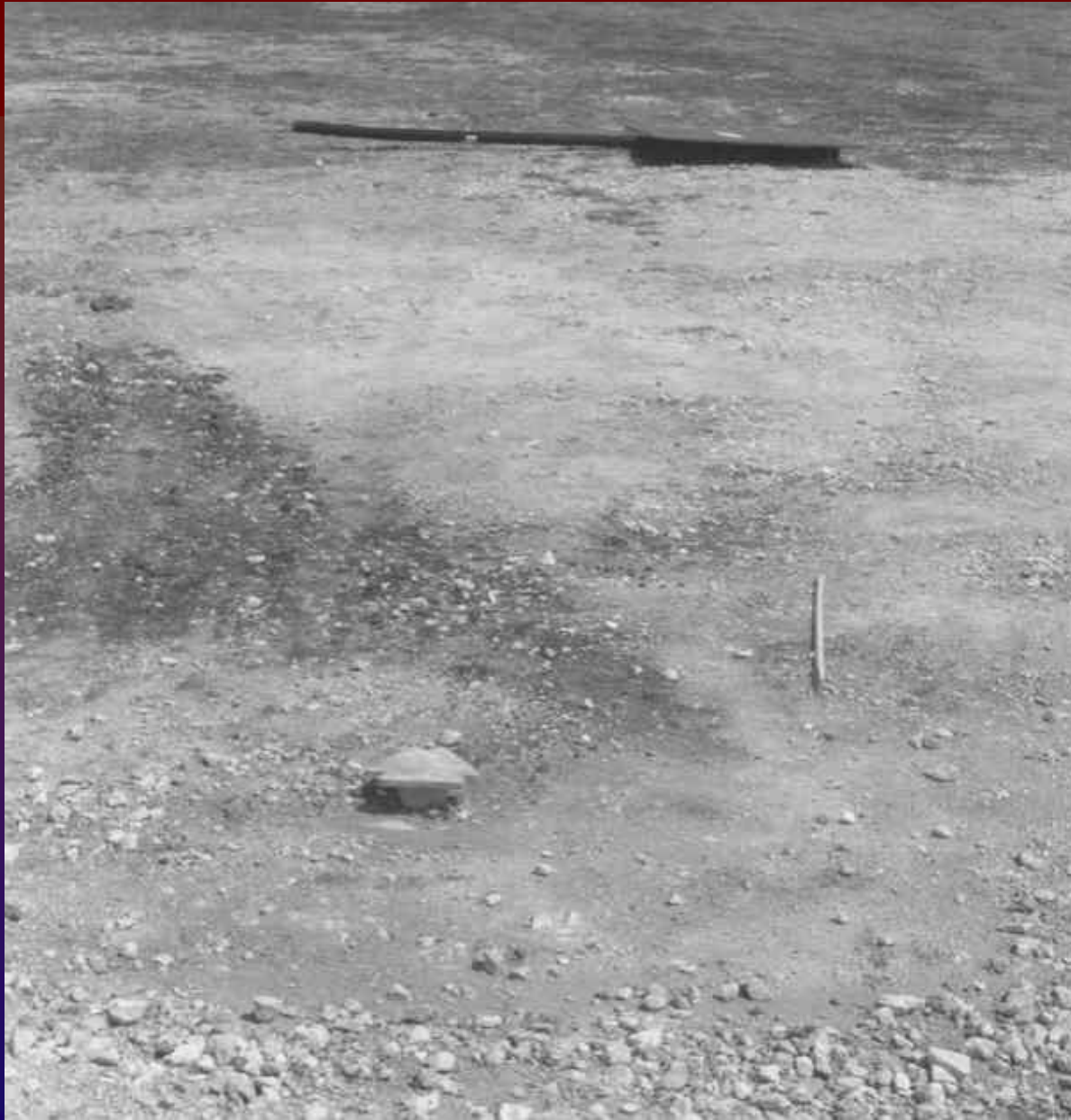
Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems

Fuse plate did not activate..
probably performed OK,
BUT
did not perform as designed..

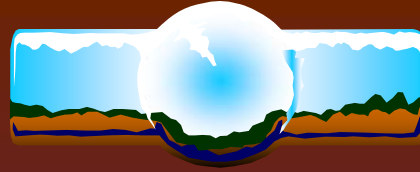




Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



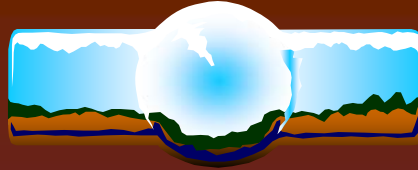
Round support with wide flange support –
Behind guardrail



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



Ground stub too high





LARGE SIGNS

□ Questions?



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



CONCLUSION

- ❑ **Different systems in use by TxDOT**
 - In-service performance evaluation = Needed
- ❑ **We looked at the different systems and discussed how we would complete the questions**
 - Guardrails
 - Transitions
 - Impact attenuation devices
 - End-treatments
 - Signs: Small & Large



QUESTIONS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



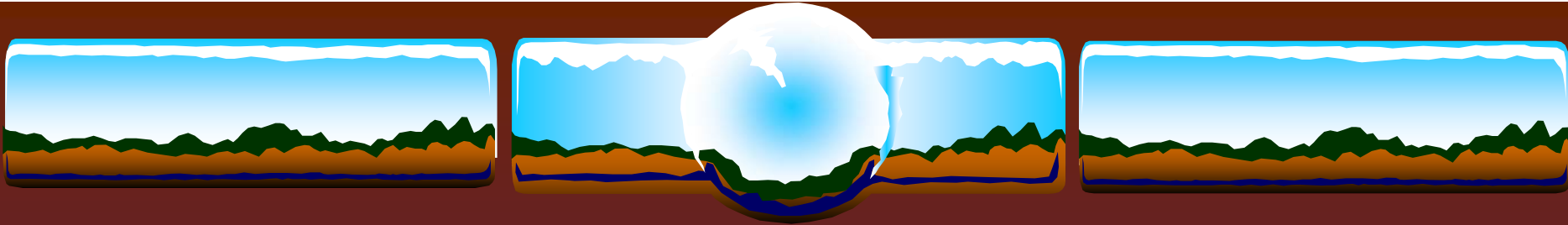
**THE
END**



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems



IN-SERVICE PERFORMANCE EVALUATION OF ROADSIDE SAFETY FEATURES (TX 0- 4366)

PILOT STUDY: PHASE II

Presented by:

Ida van Schalkwyk

Tel. (979) 458 1260

Cell: (979) 218 7322

ida@tamu.edu

<http://tti.tamu.edu/cts>



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



OVERVIEW

- The pilot study
- Phase II



**Design new
systems &
crash test**

**Accept
&
Implement**



**In-service
Evaluation**

**Maintain
&
Repair**



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



THE RESEARCH PROJECT

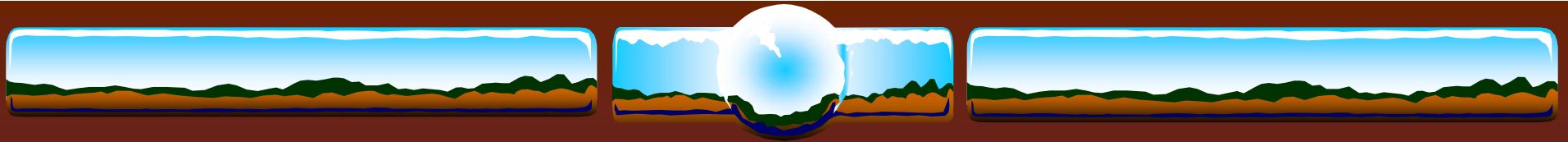
□ Purpose

- Develop process to evaluate in-service performance of roadside safety features in TX
 - Performance in the field
 - Detect problems
 - *Failures*
 - *Applications*
 - *Design load exceeded*

□ Pilot studies

- Phase I
- Phase II

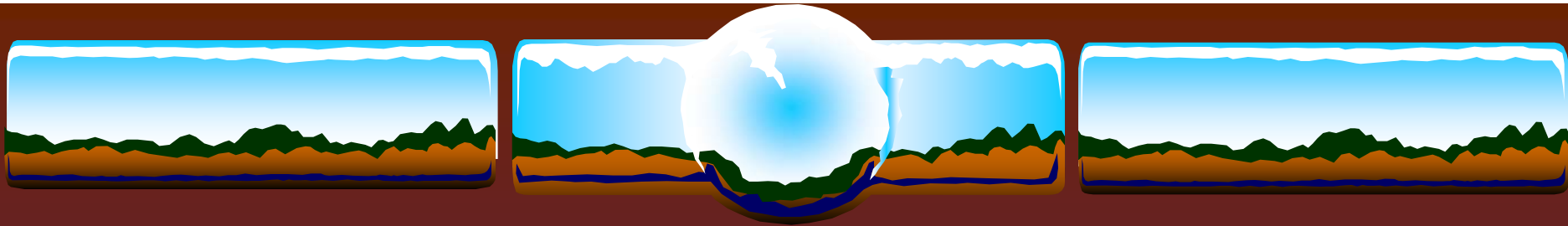




THE SYSTEMS

- Guardrails
- Impact attenuation devices
- End treatments





GUARDRAIL SYSTEMS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



OVERVIEW

- ❑ The form
- ❑ The issues
- ❑ Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form





THE FORM

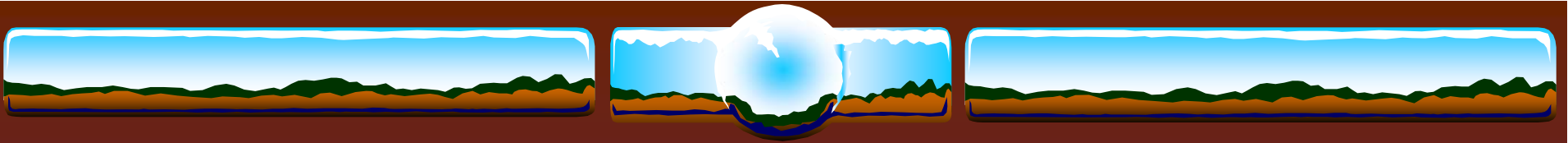
- Post type
- Post condition
- Blockout type
- Length of installation
- Installation layout
- Lateral offset
- Describe the roadside
- Height to top of rail
- Mowstrip?
- Depth of permanent deflection
- Rail condition after impact
- Length of damaged rail
- Number of damaged posts
- Damage to posts
- Impact in the transition area?



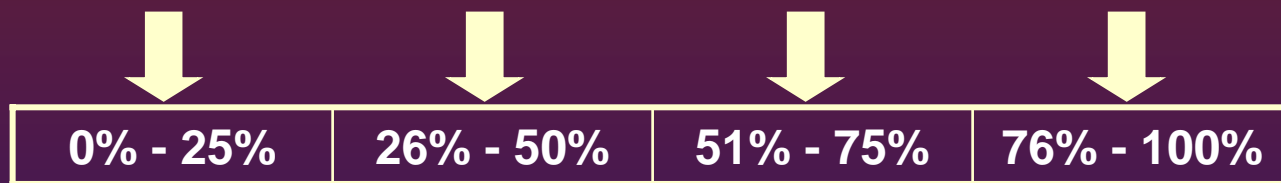
1. Post type

- Round wooden
- Rectangular wood
- Steel post





2. Post condition: Deterioration?

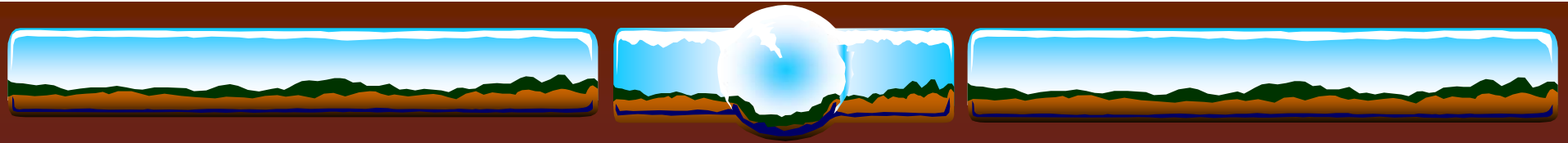




3. Blockout type

- None/ wood/ steel/ plastic





4. Length of installation



Center for
Transportation Safety
Texas Transportation Institute



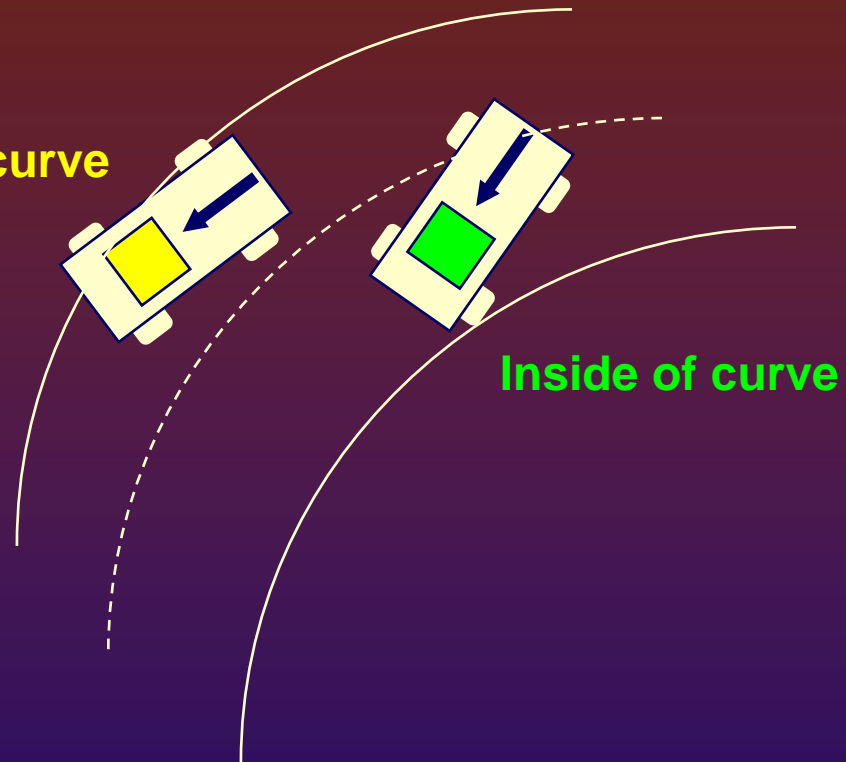
Safety and
Structural Systems



5. Installation layout

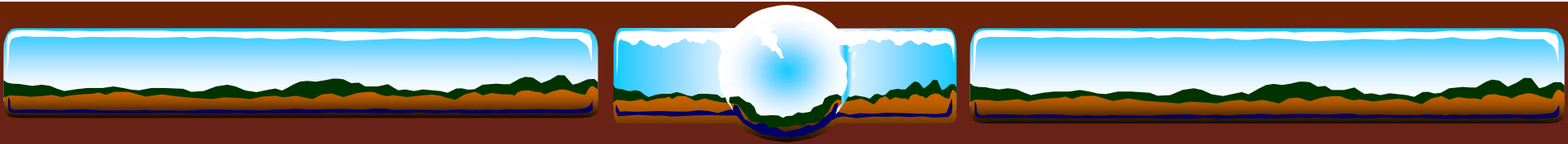
➤ On curve

Outside of curve

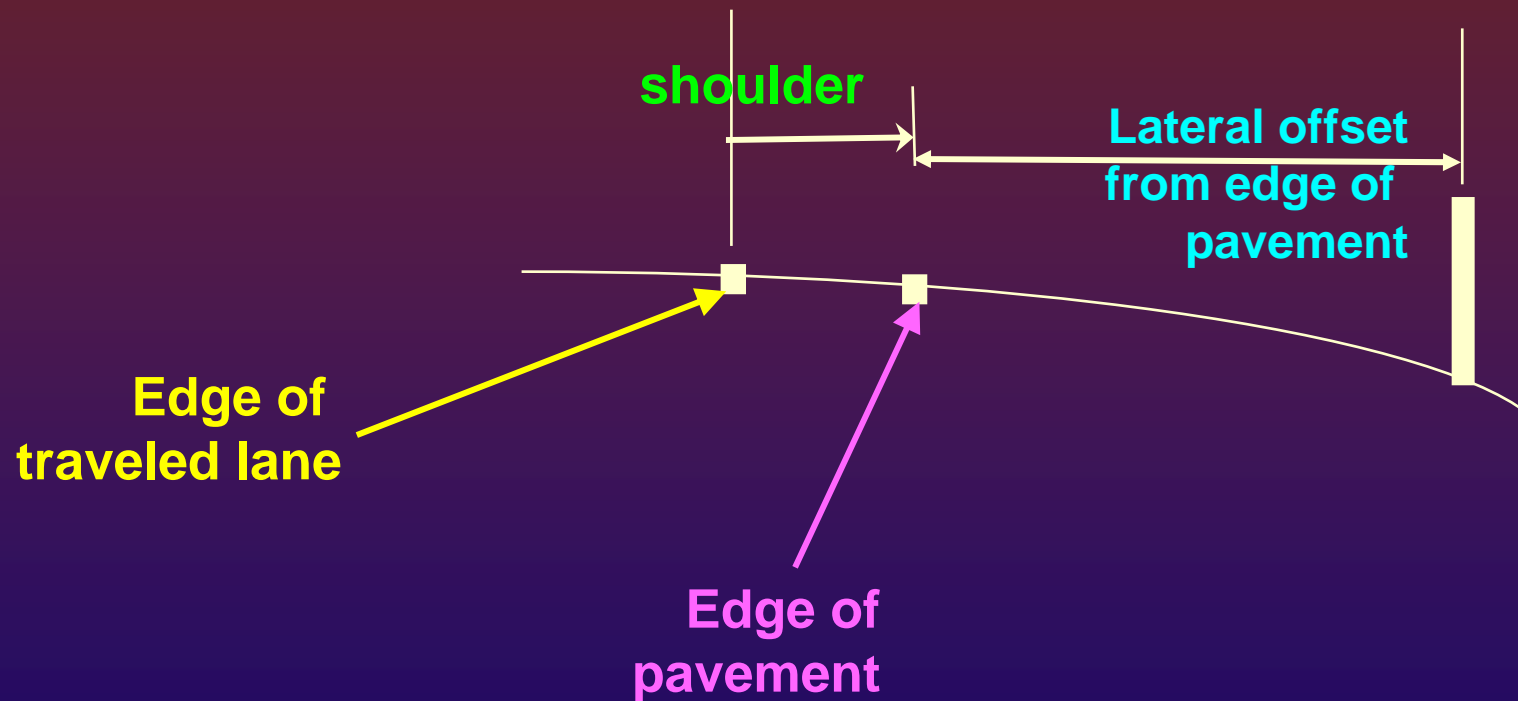


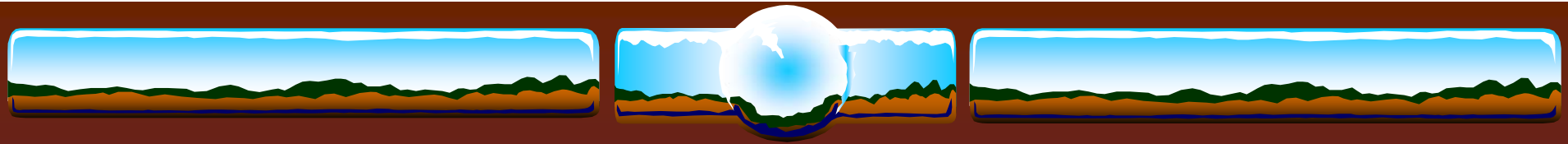
➤ On straight





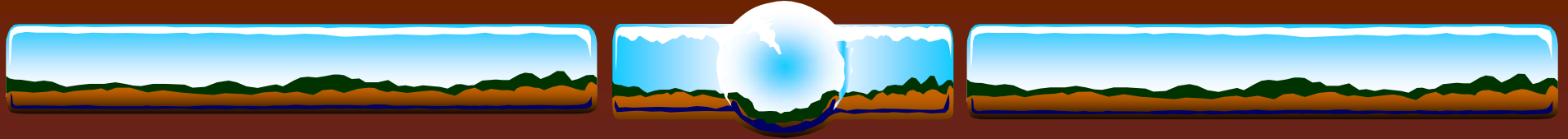
6. Lateral offset





7. Height to top of rail





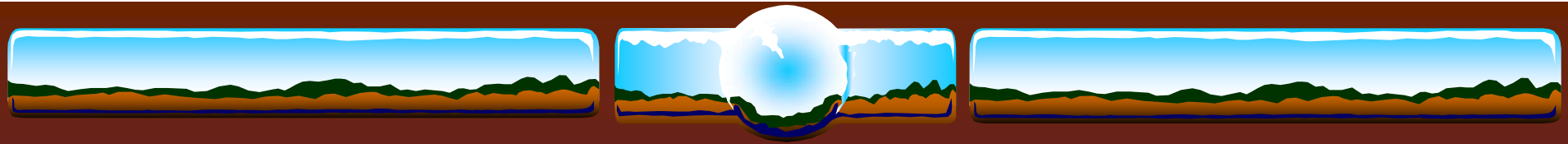
8. Mowstrip?



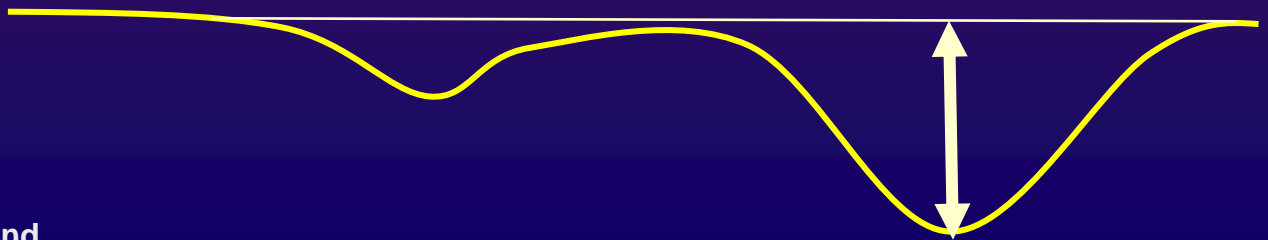
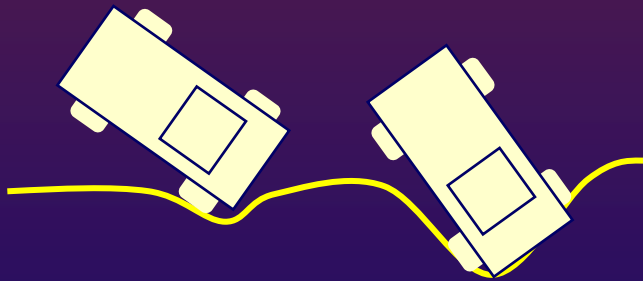
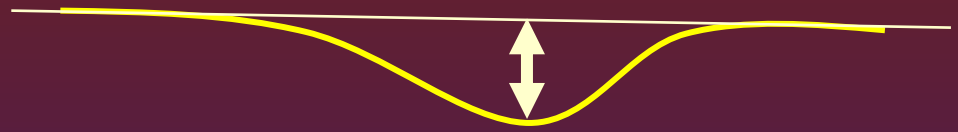
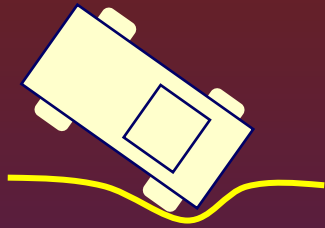
Center for
Transportation Safety
Texas Transportation Institute

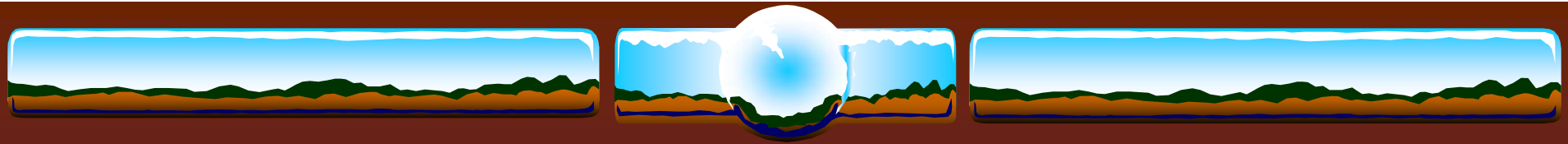


Safety and
Structural Systems



9. Depth of permanent deflection?





10. Rail condition after impact

Flattened

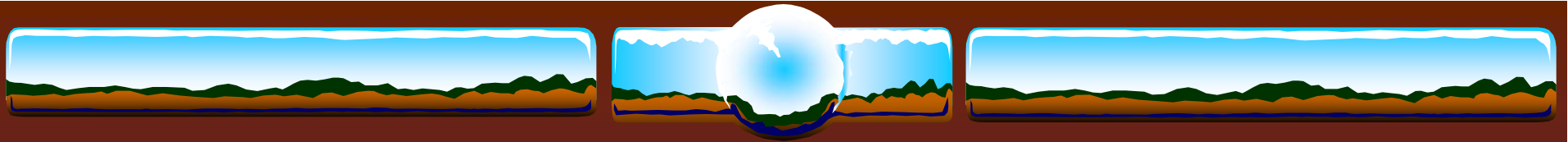


Partial tear in rail



**Ruptured:
Tear all through**





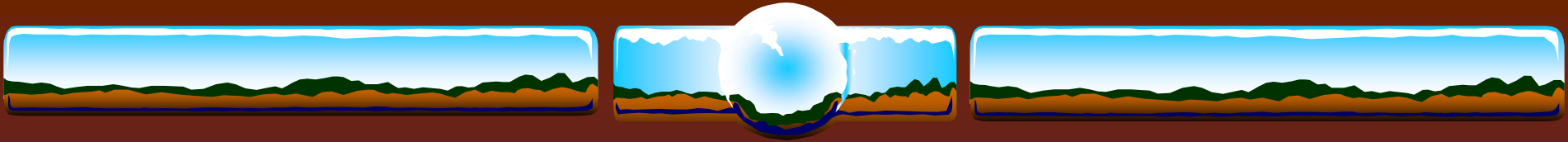
11. Length of damaged rail

11.1 Number of damaged posts

11.2 Damage to posts

- Deflected in soil
- Bent (steel)
- Fractured (wood)





12. Impact in the transition area?

- Within 25 ft of bridge rail

TRANSITION = within 25 ft

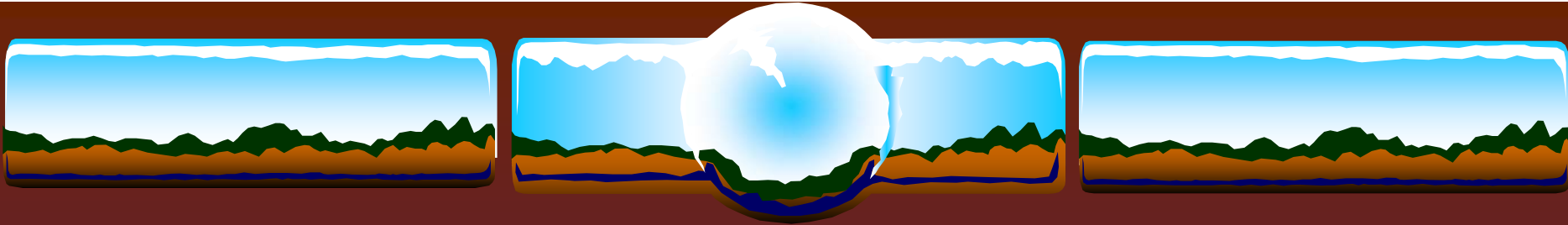




OTHER INFO

- ❑ **Did it perform as intended?**
 - Remember comment & sketch!
- ❑ **Photographs**
 - Critical
- ❑ **Maintenance cost & labor**
- ❑ **Accident report form**
 - If available
 - Valuable info for Phase II





TRANSITIONS

Guardrail to Bridge Rail



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems

1. SELECT THE TYPE OF DEVICE:

d) *TRANSITION*

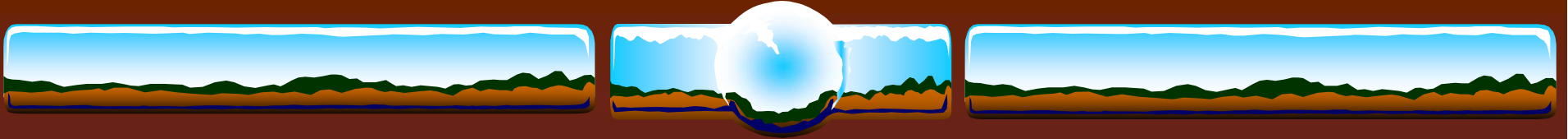
- W-BEAM GUARDRAIL TRANSITION
 THRIE BEAM TRANSITION

2. DID THE SYSTEM PERFORM AS INTENDED? (note that this question refer to a system failure or any condition where the system did not perform as we intended it to when it was installed (typically if the design load was exceeded etc.)

YES

NO





TRANSITIONS

- How is transition different from guardrail section?
- Types
 - W-beam transitions
 - Thrie beam transitions





W-BEAM TRANSITIONS

□ Transition to

- Flexible W-beam guardrail TO
- Rigid / semi-rigid bridge rails

□ How they work

- Gradual stiffening through addition of posts in 25 ft adjacent to bridge rail

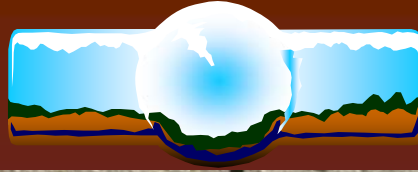
□ To T501

- W-beam, shoe & through bolts

□ To T4

- Embedded steel angle extending from end of concrete portion of bridge rail – Placed in front of the W-beam @ approx front of bridge rail





Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



THRIE BEAM TRANSITIONS

□ How they work

➤ Transition

- Flexible W-beam / thrie beam guardrail TO
- Rigid / semi-rigid bridge rail

□ Multiple transition sections

□ Incremental stiffening of rail

- Increased beam size
- Beam nesting
- Post spacing
- Post embedment depth

□ Nominal 6-inch curb used with nested thrie beam section

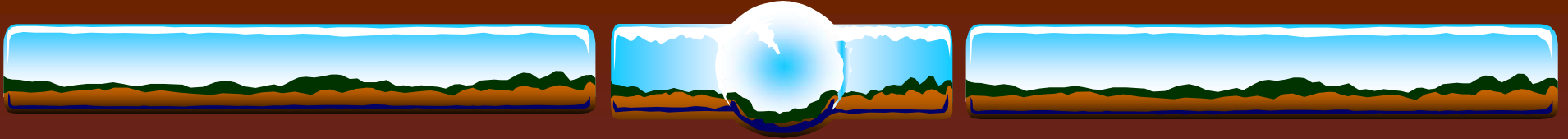




Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



TRANSITIONS *(cont)*

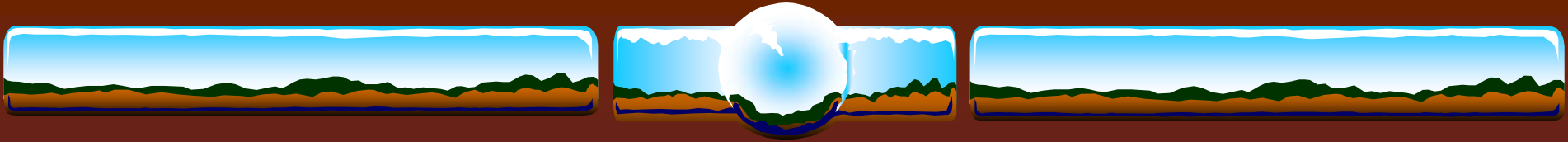
□ When they don't perform as intended

➤ Excessive deflections near end of bridge rail

▪ Cause snagging

- *Posts & rail displaced*
- *Rigid end section of bridge rail exposed*
 - Wheel and rim of vehicle
 - Vehicle instabilities
 - Potential: Large occupant compartment deformations





TRANSITIONS

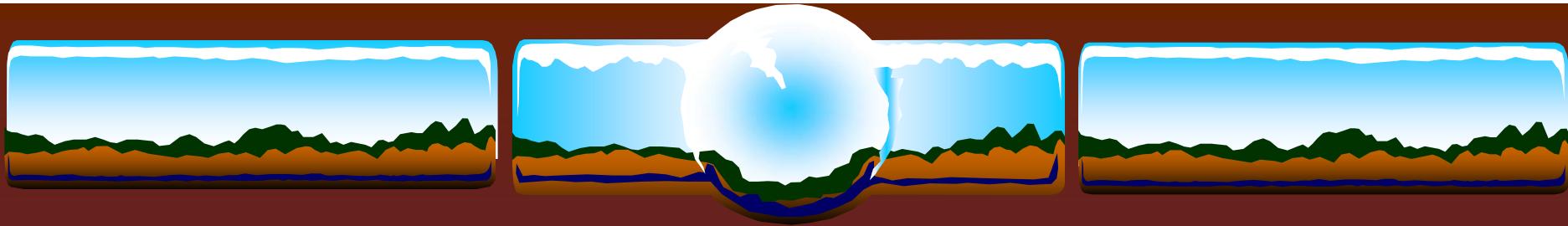
□ Questions?



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



IMPACT ATTENUATORS



Center for
Transportation Safety
Texas Transportation Institute



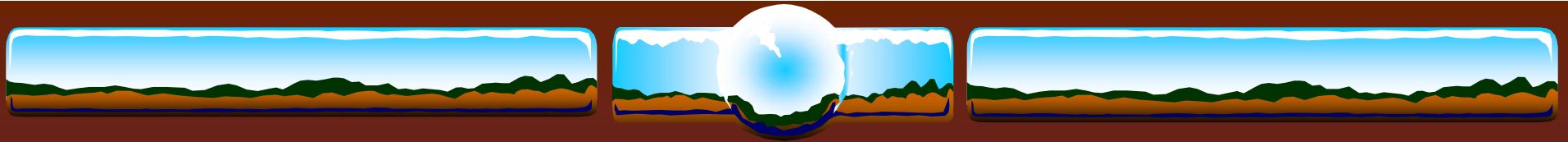
Safety and
Structural Systems



OVERVIEW

- The form
- Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form

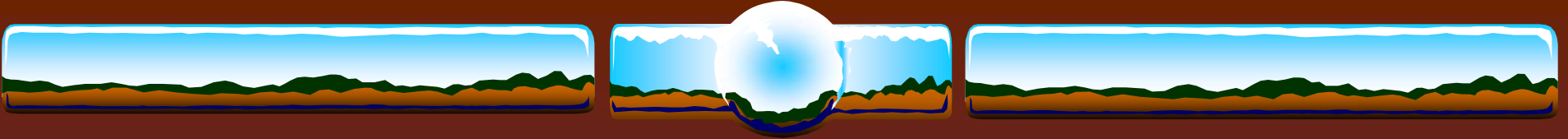




THE FORM

- ❑ Type of device
- ❑ Foundation type
- ❑ Residual / undeformed length of installation
(What is left?)
- ❑ Was it properly shielding the obstacle?
- ❑ Did all the components of the crash cushion remain attached?
 - Except sand from sand barrels
- ❑ Where did impact initially occur?
 - Post number (& sketch)





Residual / undeformed length of installation



Center for
Transportation Safety
Texas Transportation Institute



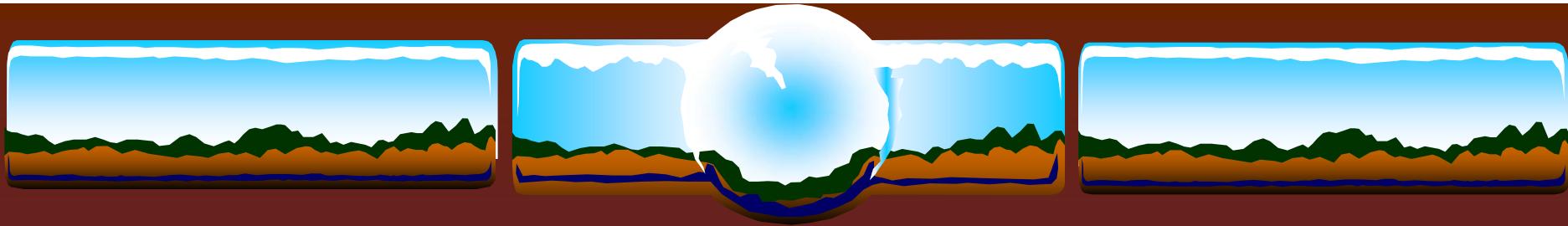
Safety and
Structural Systems



OTHER INFO

- ❑ **Did it perform as intended?**
 - Remember comment & sketch!
- ❑ **Photographs**
 - Critical
- ❑ **Maintenance cost & labor**
- ❑ **Accident report form**
 - If available
 - Valuable info for Phase II





END- TREATMENTS (SGT, GET)



Center for
Transportation Safety
Texas Transportation Institute



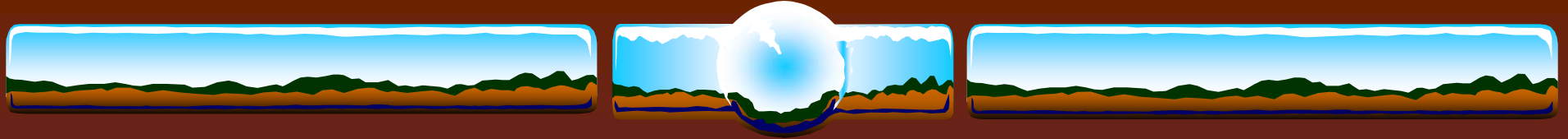
Safety and
Structural Systems



OVERVIEW

- ❑ The form
- ❑ The issues
- ❑ Other info
 - Photographs
 - Maintenance cost & labor
 - Accident report form

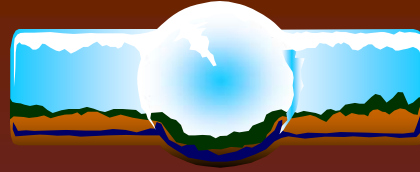




THE FORM

- ❑ **Type of device**
- ❑ **Foundation tubes**
 - Exposed?
 - Height?
- ❑ **Mowstrip?**
- ❑ **Height to top of rail?**
- ❑ **Number of damaged posts**
- ❑ **Where did impact initially occur?**
 - Post number (& sketch)
- ❑ **Was the device flared?**
 - Describe & sketch (take photo if you can)
- ❑ **Describe roadside**





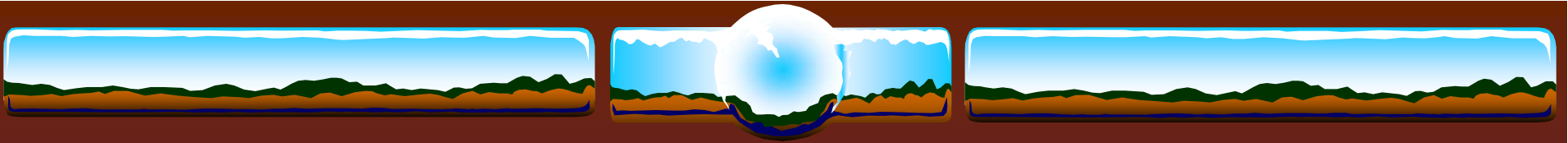
Foundation tubes



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



Height to top of rail



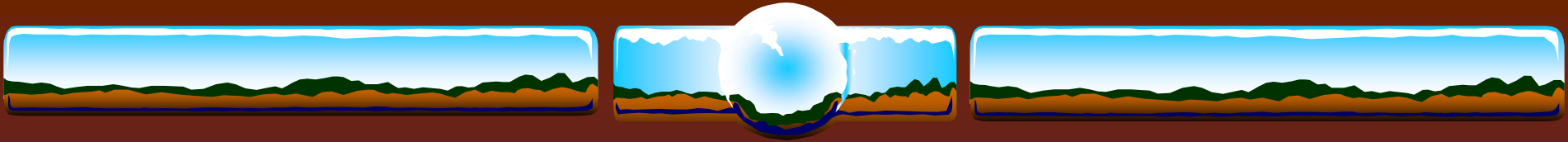
Height to top of rail



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



Describe the roadside

Flat

Up slope



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



OTHER INFO

- ❑ **Did it perform as intended?**
 - Remember comment & sketch!
- ❑ **Photographs**
 - Critical
- ❑ **Maintenance cost & labor**
- ❑ **Accident report form**
 - If available
 - Valuable info for Phase II





CONCLUSION

- **Different systems in use by TxDOT**
 - In-service performance evaluation = Needed
- **We looked at the different systems and discussed how we would complete the questions**
 - Guardrails
 - Impact attenuation devices
 - End treatments



QUESTIONS



Center for
Transportation Safety
Texas Transportation Institute



Safety and
Structural Systems



**THE
END**



Center for
Transportation Safety
Texas Transportation Institute

&

Safety and
Structural Systems

