

Manual for Assessing Safety Hardware

Second Edition



2016

PREFACE

The use of effective roadside safety features provides a reasonable level of safety for the traveling public. New systems are continually emerging to address safety problems. Devices and practices improve in response to an increased understanding of safety performance, a changing vehicle fleet, the emergence of new materials, and other factors.

This second edition of the *Manual for Assessing Safety Hardware* (MASH) is the latest in a long series of crash testing guidance documents dating back to 1962. This update incorporates many changes from the previous edition. Some of the more significant changes include:

- A new matrix for cable barrier testing on slopes
- Modifications to several test vehicle dimensions
- Updated test documentation requirements

This document's purpose is to encourage consistency in crash testing and evaluation. Full-scale crash testing has been and will continue to be the most common method of evaluating the impact performance of safety hardware. Consistency in crash testing and evaluation benefits states, testing facilities, manufacturers, and the public.

Note that MASH addresses only the crash testing of roadside safety features. It does not contain installation or maintenance guidance, nor does it supersede any of the guidelines found in the AASHTO *Roadside Design Guide*.

Implementation of this Manual by roadway agencies is outlined in an AASHTO/FHWA Joint Implementation Agreement. A copy of the agreement is available through the AASHTO Bookstore at: https://bookstore.transportation.org/item_details.aspx?ID=2707.

TABLE OF CONTENTS

Chapter 1—Introduction	1
1.1 PURPOSE AND SCOPE	1
1.2 UNDERLYING PHILOSOPHY	2
1.3 PERFORMANCE LIMITATIONS	3
1.4 SAFETY FEATURES	4
1.5 TEST LEVELS	5
1.6 INTERNATIONAL HARMONIZATION	6
1.7 ANALYTICAL AND EXPERIMENTAL TOOLS	6
1.8 ORGANIZATION OF MANUAL	7
Chapter 2—Test Matrices and Conditions	9
2.1 GENERAL	9
2.1.1 Impact Conditions	9
2.1.2 Tolerances on Impact Conditions	11
2.1.3 Safety Feature Orientation	13
2.2 TEST MATRICES	13
2.2.1 Longitudinal Barriers	13
2.2.1.1 General	13
2.2.1.2 Description of Tests	15
2.2.2 Terminals and Crash Cushions	25
2.2.2.1 General	25
2.2.2.2 Description of Tests	33
2.2.2.3 Other Terminals and Crash Cushion Systems	35
2.2.3 Truck- and Trailer-Mounted Attenuators and Variable Message Sign and Arrow Board Trailers	36
2.2.3.1 General	36
2.2.3.2 Description of Tests	39
2.2.4 Support Structures, Work-Zone Traffic Control Devices, Breakaway Utility Poles, and Longitudinal Channelizers	39
2.2.4.1 General	39
2.2.4.2 Description of Tests	43
2.2.5 Roadside Geometric Features and Pavement Discontinuities	44
2.3 IMPACT POINT FOR REDIRECTIVE DEVICES	46
2.3.1 General	46
2.3.2 Longitudinal Barriers	46
2.3.2.1 Tests with 1100C and 2270P Vehicles	48
2.3.2.2 Tests with 10000S, 36000V, and 36000T Vehicles	63
2.3.3 Terminals and Redirective Crash Cushions	63
2.3.3.1 Test 34	63
2.3.3.2 Test 36	64
2.3.3.3 Test 37	64
2.3.3.4 Test 44	65
2.4 SIDE IMPACT	65
Chapter 3—Test Installation	67
3.1 GENERAL	67
3.2 TESTING SITE	67
3.3 SOIL	68
3.3.1 Standard Soil	68
3.3.2 Soil Strength	68
3.3.3 Special Soils	72
3.3.4 Embedment of Test Article	72
3.3.5 Special Structures	73
3.4 TEST ARTICLE	73
3.4.1 General	73
3.4.2 Installation Details	74

3.4.2.1 Longitudinal Barriers	74
3.4.2.2 Terminals and Crash Cushions	76
3.4.2.3 Support Structures, Work-Zone Traffic Control Devices, and Breakaway Utility Poles	76
3.4.2.4 Truck-Mounted and Trailer-Mounted Attenuators (TMAs)	77
3.4.3 Test Installation Documentation	78
3.4.3.1 Longitudinal Barriers and Longitudinal Channelizers	78
3.4.3.2 Terminals and Crash Cushions	78
3.4.3.3 Support Structures, Work-Zone Traffic Control Devices, and Breakaway Utility Poles	79
3.4.3.4 Truck-Mounted and Trailer-Mounted Attenuators (TMAs)	79
3.4.4 Test Installation Disposal	80
Chapter 4—Test Vehicle Specifications.....	81
4.1 GENERAL	81
4.2 TEST VEHICLE DESCRIPTIONS	81
4.2.1 Production Vehicles	83
4.2.1.1 Test Vehicle Mass	86
4.2.1.2 Ballast	87
4.2.1.3 Propulsion, Guidance, and Braking	88
4.2.1.4 Vehicle Damage	88
4.2.1.5 Surrogate Occupants	89
4.2.1.6 Documentation	89
4.2.2 Surrogate Test Vehicles	96
4.2.3 Truck-Mounted and Trailer-Mounted Attenuator (TMA) Support Vehicle	97
4.3 VEHICLE INSTRUMENTATION	97
4.3.1 Instrumentation Specifications	97
4.3.2 Accelerometer and Rate Gyro Placement and Data Reduction	99
Chapter 5—Test Evaluation Criteria.....	101
5.1 GENERAL	101
5.2 EVALUATION FACTORS AND CRITERIA	101
5.2.1 Structural Adequacy	104
5.2.2 Occupant Risk	105
5.2.3 Post-Impact Vehicular Response	108
5.3 GEOMETRIC FEATURES	110
Chapter 6—Test Documentation.....	111
6.1 GENERAL REPORTING RECOMMENDATIONS	111
6.1.1 General Information	111
6.1.2 Report Contents	111
6.1.3 Findings Presentation Formats	115
6.1.4 Assessment	117
Chapter 7—In-Service Performance Evaluation	122
7.1 PURPOSE	122
7.2 OBJECTIVES	123
7.3 IN-SERVICE PERFORMANCE EVALUATION PROGRAM	123
7.3.1 New Feature Evaluation	123
7.3.2 Continuous Monitoring	126
7.4 DISCUSSION	128
Appendix A—Commentary.....	129
CHAPTER ONE	129
A1.2 UNDERLYING PHILOSOPHY	129
CHAPTER TWO	130
A2.1 GENERAL	130
A2.1.1 Impact Conditions	131
A2.1.3 Safety Feature Orientation	132
A2.2.1 Longitudinal Barriers	133
A2.2.2 Terminals and Crash Cushions	133

A2.2.3 Truck-Mounted Attenuators (TMA)	134
A2.2.4 Support Structures, Work-Zone Traffic Control Devices, Breakaway Utility Poles, and Longitudinal Channelizers.....	135
A2.3 IMPACT POINT FOR REDIRECTIVE DEVICES	137
A2.3.2.1 Tests with 1100C and 2270P Vehicles.....	138
A2.3.2.2 Tests with 10000S, 36000V, and 36000T Vehicles	141
CHAPTER THREE.....	142
A3.2 TESTING SITE.....	142
A3.3 SOIL.....	142
A3.3.1 Standard Soil	143
A3.3.2 Soil Strength	143
A3.3.3 Special Soils	144
A3.3.4 Embedment of Test Article	144
A3.4 TEST ARTICLE.....	144
A3.4.2.1 Longitudinal Barriers	144
A3.4.2.4 Truck-Mounted Attenuators (TMA).....	145
CHAPTER FOUR.....	145
A4.2 TEST VEHICLE DESCRIPTIONS.....	145
A4.2.1 Production Vehicles	146
A4.2.1.1 Test Vehicle Mass.....	147
A4.2.1.2 Ballast.....	148
A4.2.1.4 Vehicle Damage.....	148
A4.2.1.5 Surrogate Occupants	149
A4.2.2 Surrogate Test Vehicles.....	149
A4.2.3 TMA Support Truck.....	151
A4.3.1 Instrumentation Specifications	152
A4.3.2 Acceleration and Rate Gyro Placement and Data Reduction	152
CHAPTER FIVE	156
A5.1 GENERAL	156
A5.2 EVALUATION FACTORS AND CRITERIA	156
A5.2.1 Structural Adequacy	156
A5.2.2 Occupant Risk.....	157
A5.2.3 Post-Impact Vehicular Response	162
A5.3 GEOMETRIC FEATURES.....	163
CHAPTER SIX.....	164
A6.1 GENERAL REPORTING RECOMMENDATIONS.....	164
CHAPTER SEVEN	164
A7.1 PURPOSE.....	164
Appendix B—Soil Strength Performance Test	166
B1 Purpose	166
B2 Application	166
B3 Instrumented Post.....	166
B4 Post Placement	169
B5 Dynamic Test.....	169
B6 Assurance of Soil Performance	171
Appendix C—Electronic & Photographic Instrumentation Specifications	174
Appendix D—Analytical and Experimental Tools.....	212
D1 Useful Techniques.....	212
D1.1 Structural Design	212
D1.2 Static Tests.....	212
D1.3 Computer Simulations	214
D1.4 Laboratory Dynamic Tests	216
D1.5 Gravitational Pendulum.....	216
D1.6 Drop Mass/Dynamic Test Device.....	217
D1.7 Scale Model	217
D1.8 Bogie Test	217

D2 Comparison of Techniques	218
Appendix E—Measurement of Vehicle Deformation	220
E1 Pre-Impact Measurements	220
E2 Post-Impact Measurements	222
E3 Photographic Documentation	222
E4 Procedure for Measuring Exterior Crush	224
Appendix F—Determination of THIV, PHD, and ASI	228
F1 Introduction	228
F2 A Guide to the Measurement of the Theoretical Head Impact Velocity (THIV) and the Post-Impact Head Deceleration (PHD)	228
F2.1 General	228
F2.2 Theoretical Head Impact Velocity (THIV)	228
F2.3 Post-Impact Head Deceleration (PHD)	232
F2.4 Summary of Procedure to Compute THIV and PHD	232
F3 A Guide to the Measurement of the Acceleration Severity Index (ASI)	234
F3.1 Procedure	234
F3.2 Summary	235
Appendix G—Occupant Risk Estimation for 1500A Vehicle.....	237
G1. Introduction.....	237
G2. Occupant Risk Values for 1500A Vehicle	238
G2.1 Procedure Details	238
Appendix H—Test Vehicle Selection Procedures	242
Glossary	249
References and Bibliography.....	254

LIST OF FIGURES

Figure 2-1. Impact Conditions for Longitudinal Barrier Tests	20
Figure 2-2A. Critical Cable Barrier Placement for 4H:1V V-Ditch	21
Figure 2-2B. Critical Cable Barrier Placement for 6H:1V V-Ditch.....	22
Figure 2-3A. Impact Conditions for Terminal and Redirective Crash Cushion Tests	30
Figure 2-3B. Impact Conditions for Non-Redirective Crash Cushion Tests	32
Figure 2-4. Impact Conditions for TMA.....	38
Figure 2-5. Impact Conditions for Support Structures, Work-Zone Traffic Control Devices, and Breakaway Utility Poles.....	43
Figure 2-6. Critical Impact Point for Test 10, Test Level 1	51
Figure 2-7. Critical Impact Point for Test 10, Test Level 2	52
Figure 2-8. Critical Impact Point for Test 10, Test Levels 3, 4, 5, and 6	53
Figure 2-9. Critical Impact Point for Test 11, Test Level 1.....	54
Figure 2-10. Critical Impact Point for Test 11, Test Level 2.....	55
Figure 2-11. Critical impact point for Test 11, Test Levels 3, 4, 5, and 6.....	56
Figure 2-12. Critical Impact Point for Test 20, Test Level 1	57
Figure 2-13. Critical Impact Point for Test 20, Test Level 2	58
Figure 2-14. Critical Impact Point for Test 20, Test Levels 3, 4, 5, and 6	59
Figure 2-15. Critical Impact Point for Test 21, Test Level 1	60
Figure 2-16. Critical Impact Point for Test 21, Test Level 2	61
Figure 2-17. Critical Impact Point for Test 21, Test Levels 3, 4, 5, and 6	62
Figure 2-18. Critical Impact Point for Test 34 on Non-Gating Crash Cushions.....	64
Figure 3-1. Recommended Summary Sheet for Strong Soil Test Results	70
Figure 3-2. Example of Test Day Static Soil Strength Documentation	71
Figure 4-1. 1100C and 1500A Vehicle Parameters	91
Figure 4-2. 2270P Vehicle Parameters	92
Figure 4-3. 10000S Vehicle Parameters.....	93
Figure 4-4. 36000V Vehicle Parameters	94
Figure 4-5. 36000T Vehicle Parameters.....	95
Figure 4-6. Recommended Vehicle Coordinate System	99
Figure 5-1. Exit Box for Longitudinal Barriers	109
Figure 6-1. Recommended Format of Summary Sheet for Crash Test Results	120
Figure 6-2. Example of Recommended Summary Sheet for Crash Test Results	121
Figure 7-1. Flowchart of the In-Service Performance Evaluation Process.....	125
Figure A-1. Accelerometer Placement	154
Figure B-1. Instrumented Post	167
Figure B-2. Dynamic Test Configuration.....	169
Figure B-3. Dynamic and Static Test Results for Standard Post Test.....	170
Figure B-4. Static Soil Test.....	172
Figure B-5. Test Day Static Load Test Compared to Standard Test.....	173
Figure E-1. Pre-Impact Measurement.....	220
Figure E-2. Placement of Swivel Laser Bracket.....	221
Figure E-3. Measurement of Vertical Positions	222
Figure E-4. Vehicle Deformation Spreadsheet.....	223
Figure E-5. Reference Line Configuration.....	224
Figure E-6. Field Length Measurement.....	225
Figure E-7. Crush Depth Measurements.....	226
Figure E-8. Crush Depth Measurements.....	227
Figure F-1. Vehicle and Ground Reference Frames.....	229
Figure F-2. Impact of the Theoretical Head on the Left Side	231

LIST OF TABLES

Table 1-1. Test Levels	6
Table 2-1. Vehicle Gross Static Mass Upper and Lower Limits	13
Table 2-2A. Recommended Test Matrices for Longitudinal Barriers.....	15
Table 2-2B. Recommended TL-3 Test Matrix for Single Median Barrier Designed for Placement Anywhere in 4H:1V V-Ditch	16
Table 2-2C. Recommended TL-3 Test Matrix for Single or Double Median Barrier Designed for Placement Between 0- to 4-ft Offset from Slope Break	17
Table 2-2D. Recommended TL-3 Test Matrix for Single Median Barrier Designed for Placement Anywhere in 6H:1V V-Ditch	18
Table 2-2E. MASH TL-3 Test Matrix for Single or Double Median Barrier Placed at 0- to 4-ft Offset from SBP of 6H:1V V-Ditch.....	19
Table 2-3. Recommended Test Matrices for Terminals and Crash Cushions	27
Table 2-4. Recommended Test Matrices for Truck- and Trailer-Mounted Attenuators.....	37
Table 2-5. Recommended Test Matrices for Support Structures, Work-Zone Traffic Control Devices, and Breakaway Utility Poles.....	42
Table 2-6. Recommended Post Spacing for Evaluating Cable Barriers Placed within Median Ditches	47
Table 2-7. Critical Impact Point for Rigid Barrier Tests with 1100C and 2270P Vehicles	50
Table 2-8. Critical Impact Point for Heavy Vehicle Tests.....	63
Table 4-1. Recommended Properties of 1100C, 1500A, and 2270P Test Vehicles.....	85
Table 4-2. Recommended Properties of 10000S, 36000V, and 36000T Test Vehicles	86
Table 5-1A. Safety Evaluation Guidelines for Structural Adequacy	102
Table 5-1B. Safety Evaluation Guidelines for Occupant Risk.....	103
Table 5-1C. Safety Evaluation Guidelines for Post-Impact Vehicular Response	104
Table 6-1. Recommended Table of Contents for Crash Test Reports	114
Table 6-2. Recommended Format for Reporting of Findings.....	118
Table 6-3. Example of Recommended Assessment Summary Page for Individual Crash Tests	119
Table 6-4. Example of Recommended Assessment Summary Page for Multiple Crash Tests.....	119
Table A-1. Properties of Common Barrier Rail Elements	139
Table A-2. Wood Post Properties	140
Table A-3. Dynamic Yield Forces of Posts Embedded in Strong Soil.....	141
Table D-1. Sources for Safety Feature Information.....	213
Table D-2. Summary of Highway Safety Computer Programs	215
Table D-3. Safety Feature Development Techniques.....	218
Table H-1. Small Car Weights and Sales Volumes	244
Table H-2. Light Truck Weights and Sales Volumes	245
Table H-3. Center-of-Gravity Heights of Sport Utility Vehicles and Pickups.....	247
Table H-4. Candidate Test Vehicle Dimensions.....	248

Introduction

1

1.1 PURPOSE AND SCOPE

The purpose of this manual is to present uniform guidelines for the crash testing of both permanent and temporary highway safety features and recommended evaluation criteria to assess test results. Guidelines are also presented for the in-service evaluation of safety features. These guidelines and criteria, which have evolved over the past 40 years, incorporate current technology and the collective judgment and expertise of professionals in the field of roadside safety design. They provide: (1) a basis on which researchers and user agencies can compare the impact performance merits of candidate safety features, (2) guidance for developers of new safety features, and (3) a basis on which user agencies can formulate performance specifications for safety features.

A goal of a highway safety feature is to provide a forgiving roadway and roadside that reduces the risk of a serious crash when a motorist leaves the roadway. The safety goal is met when the feature either contains and redirects the vehicle away from a roadside obstacle, decelerates the vehicle to a safe stop, readily breaks away or fractures or yields, allows a controlled penetration, or is traversable, without causing serious injuries to the vehicle's occupants or to other motorists, pedestrians, or work zone personnel.

Ideally, the roadside would be clear of all obstructions, including unnecessary roadside hardware, and be traversable so that an errant motorist could recover control of the vehicle and stop or return to the travelway. However, there are numerous roadside areas that cannot practically be cleared of all fixed objects or made traversable. At these sites, the use of an appropriate safety feature or safety treatment is intended to reduce the consequences of a departure from the roadway.

The crash testing guidelines presented herein cover vehicular tests to evaluate the impact performance of permanent and temporary highway safety features. Performance is evaluated in terms of the risk of injury to occupants of the impacting vehicle, the structural adequacy of the safety feature, the exposure to workers and pedestrians that may be behind a barrier or in the path of debris resulting from impact with a safety feature, and the post-impact behavior of the test vehicle. Other factors that should be evaluated in the design of a safety feature, such as aesthetics, costs (initial and maintenance), and durability (ability to withstand environmental conditions such as freezing and thawing, wind-induced fatigue loading, effects of moisture, ultraviolet radiation, etc.) are not addressed in this document.

The procedures described herein include guidelines for direct impact performance evaluation through full-scale crash testing as well as general procedures for evaluating the field performance of a safety feature. New safety features or significant revisions to existing designs should first be evaluated through full-scale crash testing. After a system has been proven to meet the recommended impact performance guidelines, the evaluation should switch to an in-service evaluation of the feature's field performance. It is recommended that in-service performance evaluations be conducted when new safety features are placed in service.

The crash testing guidelines provide a minimum set of requirements that a roadside safety feature has to meet in order to demonstrate its satisfactory impact performance. However, it should be noted that, while these guidelines are representative and applicable to an array of highway features and traffic conditions, they are by no means all-inclusive. Experience has shown that as new designs are developed, current test procedures may not properly evaluate critical conditions for these designs. Experience has also shown that evaluation and testing of features not addressed by the current guidelines will be made. Therefore, specific features and site conditions may arise that require special tests and evaluation criteria. Deviations from the guidelines are warranted when other tests or evaluation criteria are more appropriate and representative of site or design conditions. However, it should also be understood that it is impractical to test a particular feature for all conditions that may be encountered in the field and engineering judgment should be exercised when developing policies for the use of these features under differing conditions.

These crash testing and impact performance guidelines supersede those contained in *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features* (129). Major revisions incorporated herein relative to Report 350 include (a) changes to the test vehicles, (b) changes to the number and impact conditions of the test matrices, (c) changes to the evaluation criteria, and (d) addition of new features to the test guidelines.

1.2 UNDERLYING PHILOSOPHY

The underlying philosophy in the development of the guidelines is that of “worst practical conditions.” When selecting test parameters, such as the test vehicle, impact speed and angle combination, point of impact, test matrix, etc., every effort is made to specify the worst, or most critical, conditions. For example, the weight of the small passenger car test vehicle was selected to represent approximately the 2nd percentile of passenger type vehicles, i.e., only two percent of vehicles weigh less than the specified test weight. The impact speed and angle combination represents approximately the 93rd percentile of real-world crashes, i.e., only seven percent of crashes are more severe. When the combined effects of all testing parameters are considered, the testing represents the extremes of impact conditions to be expected in real-world situations. It is also implicitly assumed that, if a roadside safety feature performs satisfactorily at the two extremes, then the feature would also work well for all impact conditions in between. This assumption has shown to be reasonable for most roadside safety features.

On the other hand, the selection of the test parameters must be practical so that the roadside safety features developed in accordance with the guidelines are cost-effective and provide increased levels of safety without placing an unrealistic financial burden on user agencies. Considerations need to be given to available technology and associated costs. The relevancy of the test parameters should also be taken into account, such as increases in the level of safety and potential effects on existing and newly developed features. In many respects, the selection of test parameters is a policy decision as to what level of safety should be provided and at what cost to the user agencies.

Another underlying philosophy used in developing the guidelines for selected roadside safety features is that of the “state-of-the-possible.” Examples for such features include breakaway sign and luminaire supports and Category II temporary work-zone traffic control devices. For these roadside safety features, technology is already available for designing and manufacturing devices that can meet evaluation criteria more stringent than those specified for other roadside safety features, thus the term “state-of-the-possible.” For example, the limit of the occupant impact velocity (OIV) for breakaway pole structures is set at 16 ft/s (5.0 m/s) instead of 39 ft/s (12.0 m/s) and more stringent guidelines are recommended for evaluating windshield damage for Type I and Type II temporary work-zone traffic control devices. The rationale for this underlying philosophy is that, since technology is readily available to meet these more stringent criteria without undue financial burden, it is to the benefit of motorists to provide a higher level of safety.

1.3 PERFORMANCE LIMITATIONS

It should be recognized that the impact performance of a highway feature cannot be measured by a series of crash tests alone. Crash testing must be viewed as a necessary, but not sufficient, condition to indicate that a feature would perform satisfactorily under real-world conditions. First, crash testing is conducted under idealized conditions so that impact performance can be evaluated and compared under controlled conditions. Second, even the most carefully researched device has performance limits dictated by physical laws, vehicle stability, and vehicle crashworthiness.

For example, at some sites, sufficient space is lacking to safely decelerate a vehicle, regardless of the crash cushion design. Irrespective of the breakaway feature, certain structural supports may be so massive that the impacting vehicle is abruptly decelerated, thus limiting achievable impact performance without a change in support technology. There is no assurance that a feature meeting the test recommendations herein for a tracking vehicle will perform satisfactorily if impacted by a vehicle sliding sideways or rotating. Some vehicle types may lack sufficient size or mass or necessary crashworthiness features such as interface strength, stiffness, controlled crush properties, and stability to provide occupants with an acceptable level of protection, e.g., no provisions are made herein for the design and testing of safety features for two-wheeled vehicles. Seemingly insignificant site conditions such as curbs, slopes, and soft soil conditions can contribute to the unsuccessful performance of a safety feature for some impact conditions.

For these reasons, safety features are generally developed and tested for selected idealized situations that are intended to encompass a large majority, but not all, of the possible in-service collisions. Even

so, it is essential that test results be evaluated and interpreted by competent researchers and that the evaluation be guided by sound engineering judgment. It is to be expected that certain features, while meeting all test and evaluation criteria recommended herein, may encounter in-service conditions that are not covered by the testing. Variations in material characteristics, such as increases and decreases in steel yield strength from one batch to the next or the thermal sensitivity of the modulus of elasticity of polymer materials, have been shown to significantly alter the strength and/or stiffness of roadside safety features. Further, variations in field installation details can materially affect the performance of some roadside safety features. Thus, the user agency may, at its discretion, require additional testing and evaluation requirements beyond those set forth herein. The corollary of this is also to be expected, i.e., certain features not meeting all test and evaluation criteria recommended herein may still be cost-effective alternatives for selected in-service applications. In this case, highway agencies could continue to utilize safety features that have demonstrated good impact performance through an in-service performance evaluation.

Finally, it should be emphasized that these guidelines are intended for crash testing and evaluation of roadside safety features and not as use warrants. In other words, these guidelines do not address when, where, and how roadside safety features are to be employed in the field. User agencies should follow the guidelines set forth in the AASHTO *Roadside Design Guide* (4) and formulate internal policies for directions regarding use warrants.

1.4 SAFETY FEATURES

The impact performance evaluation guidelines cover both permanent and temporary highway safety features, including:

- Longitudinal barriers
 - Flexible and semi-rigid barriers
 - Rigid barriers
 - Barrier transitions
- Terminals
 - Guardrails
 - Median barriers
- Crash cushions
 - Redirective
 - Non-redirective
- Support structures
 - Breakaway luminaires and signs
 - Utility poles
 - Work-zone traffic control devices

- Work zone attenuation and channelizers
 - Truck-mounted attenuators (TMAs)
 - Longitudinal channelizers
 - Other
- Other devices
 - Traffic gates
 - Arrestors
- Drainage and geometric features

It should be noted that this list of roadside safety features is not all-inclusive and new features may be developed that are not covered by this list. Current testing and evaluation procedures may not properly address the critical conditions and impact performance for these new designs. Special tests and evaluation criteria may, therefore, be needed for proper evaluation. Also, the list does not include barriers or devices intended for other purposes, such as security barriers designed to stop impacting vehicles with little regard for the occupant risk. Testing and evaluation requirements for such devices should refer to the appropriate agencies, such as the U.S. Department of State or ASTM specifications.

1.5 TEST LEVELS

Longitudinal barriers may be tested to six test levels and other roadside features may be tested to three test levels. A test level is defined by impact conditions (speed and angle of approach) and the type of test vehicle (ranging in size from a small car to a fully loaded tractor-trailer truck), as summarized in Table 1-1. The first three test levels are limited to passenger vehicles while the last three incorporate some form of heavy truck. Note that longitudinal barriers are the only safety features for which all six test levels are defined at this time. All other safety features are designed exclusively for passenger vehicles, such as automobiles and light trucks. A feature designed and tested for a low test level would generally be used on a low-speed, low-volume, or both roadway such as a rural collector, local road, or urban street. A feature designed and tested for a high test level would typically be used on a high-speed, high-volume, or both, roadway, such as a freeway. It must also be noted that features that meet a given test level will generally have different performance characteristics. Although a rigid barrier and a flexible barrier can be designed to satisfy a given test level, they will have different applications. The rigid barrier will produce higher vehicle decelerations and prevent any lateral deflection while the flexible barrier will produce lower accelerations, allow large lateral deflections, and be less likely to redirect the impacting vehicle back toward the travelway. Further, there are different performance classifications for some safety features, such as crash cushions. For example, a crash cushion can be designed to redirect a vehicle impacting the side of the cushion (termed a *redirective crash cushion*), or it can be designed to decelerate the vehicle to a stop when impacted on the side (termed a *non-redirective crash cushion*). Both designs can be made to satisfy a given test level.

While the guidelines were formulated purposely to offer the user considerable latitude in the design and testing of a feature, it is not the purpose nor is it within the purview of this document to determine

where a feature, satisfying a given test level and having specific performance characteristics, would find appropriate applications along the nation's roadways. That determination rests with the transportation agency responsible for the design, operation, and maintenance of the roadway.

TABLE 1-1. Test Levels

Test Level	Test Vehicle Designation* and Type	Test Conditions	
		Speed mph (km/h)	Angle (degrees)
1	1100C (Passenger Car) 2270P (Pickup Truck)	31 (50) 31 (50)	25 25
2	1100C (Passenger Car) 2270P (Pickup Truck)	44 (70) 44 (70)	25 25
3	1100C (Passenger Car) 2270P (Pickup Truck)	62 (100) 62 (100)	25 25
4	1100C (Passenger Car) 2270P (Pickup Truck) 10000S (Single-Unit Truck)	62 (100) 62 (100) 56 (90)	25 25 15
5	1100C (Passenger Car) 2270P (Pickup Truck) 36000V (Tractor-Van Trailer)	62 (100) 62 (100) 50 (80)	25 25 15
6	1100C (Passenger Car) 2270P (Pickup Truck) 36000T (Tractor-Tank Trailer)	62 (100) 62 (100) 50 (80)	25 25 15

* See Chapter 2 for detailed description of each vehicle designation.

1.6 INTERNATIONAL HARMONIZATION

Concurrent with the preparation of the first edition of this document, the European Committee for Standardization (CEN) was preparing a similar document for the European Union (EU). Developments in both the United States and CEN were monitored, and every effort was made to harmonize the impact performance standards, e.g., using the same or similar testing conditions and evaluation criteria. However, given the inherent differences in highway and traffic conditions between the United States and the EU, differences between the U. S. guidelines and CEN standards are to be expected.

1.7 ANALYTICAL AND EXPERIMENTAL TOOLS

Design and development of a new safety feature is a complicated process in which full-scale crash testing is used to demonstrate the satisfactory impact performance of the feature. During the early stages of design and development, analytical and experimental tools are typically used to aid in the process, including:

- principles of mechanics,
- static tests,
- dynamic tests, and
- computer simulation.

The initial design is typically developed using structural loading and design procedures based on the principles of mechanics. Static tests are often conducted on certain critical components and connections to develop such data as ultimate capacity of the materials, strength of connections, load/deflection characteristics, etc. Dynamic tests using a pendulum or bogie vehicle are used to test subsystems or prototypes of the feature, e.g., to determine the energy absorption characteristics of a material under dynamic impact conditions. Results from the static and dynamic testing are then incorporated into computer models to simulate and evaluate the impact performance of the feature under varying conditions, including parametric studies. The initial design is then modified based on results of the static and dynamic tests and the computer simulation.

Note that designers/developers may differ in their approaches and may or may not use one or more of these analytical and experimental tools, depending on the feature. Some features are relatively simple to design or their characteristics are well-known from previous work such that the initial design can be crash tested without any of these intermediate steps. Other features are very complicated and may require the use of every tool available. These analytical and experimental tools can be invaluable to the design and development process and should be used to the fullest extent possible. A more detailed discussion on these analytical and experimental tools is presented in Appendix D.

Computer modeling using a finite element analysis code, such as LS-DYNA, has made significant advances over recent years and is now a major tool in the development and testing of roadside safety features. Computer modeling provides a means for developers of safety features to assess the impact performance of safety features without actual crash testing. The evaluation can range from individual components to subsystems, or to the entire system. While computer modeling is gaining more acceptance and reliance in the development and testing process, its effectiveness still depends heavily on the expertise of the individual that builds the models. Further, without extensive examination of a simulation program's input parameters, it is impossible for another party to critically evaluate the model's accuracy. Therefore, it is premature at this time to consider replacing the crash testing recommended herein with computer modeling to evaluate the impact performance of roadside safety features.

1.8 ORGANIZATION OF MANUAL

Chapter 2 outlines the test matrices and conditions recommended for testing and evaluating various roadside safety features. It also presents recommended tolerances on impact conditions and procedures to identify the critical impact point for certain features. Chapter 3 describes the requirements for construction of the test installations, including soil type and conditions. Chapter 4 describes the test vehicles, specifications, and recommended instrumentation. It also identifies parameters that should be measured before, during, and after the test. Chapter 5 presents the evaluation criteria used for assessing test results. Chapter 6 recommends the manner in which a given test and its results are to be document-

ed. Chapter 7 contains guidelines on how in-service performance evaluation of a feature should be conducted. Appendix A is a commentary on Chapters 1 through 7 and presents further elaboration and discussion. Appendix B presents procedures for validating and conducting in-situ soil testing procedures. Appendix C contains electronic and photographic instrumentation specifications, reproduced with permission from the Society of Automotive Engineers. Appendix D presents a number of analytical and experimental tools. Appendix E presents techniques for measuring occupant compartment and vehicle deformation. Appendix F presents procedures for calculating Theoretical Head Impact Velocity (THIV), Post-Impact Head Deceleration (PHD), and Acceleration Severity Index (ASI) as measures of occupant risk. Appendix G contains a proposed methodology for analyzing staged attenuation systems for mid-sized vehicle impacts. Appendix H outlines a procedure for re-evaluating and selecting new test vehicles in response to changes in the vehicle fleet. A glossary of terms and a bibliography complete the document.