American Association of State Highway

and Transportation Officials

executive committee

2015–2016

President: Paul Trombino, Iowa

Vice President: David Bernhardt, Maine

Secretary/Treasurer: Carlos Braceras, Utah

 **Regional Representatives**

 **REGION I**

 Leslie Richards, Pennsylvania, One-Year Term

 Pete Rahn, Maryland, Two-Year Term

 **REGION II**

 Paul Mattox, West Virginia, One-Year Term

 Charles Kilpatrick, Virginia, Two-Year Term

 **REGION III**

 Charles A. Zelle, Minnesota, One-Year Term

 Randall S. Blankenhorn, Illinois, Two-Year Term

 **REGION IV**

 Brian Ness, Idaho, One-Year Term

 Carlos Braceras, Utah, Two-Year Term

 **Non-Voting Members**

 Immediate Past President: (Vacant)

 Executive Director: Bud Wright, Washington, DC

Highways Subcommittee on DESIGN
2016

Carlos Braceras, Utah, Chair

Joyce Taylor, Maine, Vice Chair

Robert Mooney, FHWA, Secretary

Patricia Bush, AASHTO Liaison

ALABAMA, William Adams, Rex Bush, William Kelly

ALASKA, Mark Neidhold, Kenneth Morton

ARIZONA, Steve Boschen, Annette Riley

ARKANSAS, Mike Fugett, Trinity Smith

CALIFORNIA, Timothy Craggs, Cathrina Barros

COLORADO, Neil Lacey

CONNECTICUT, Scott Hill, Rabih Barakat, Timothy Wilson

DELAWARE, Brian McIlvaine, Mark Tudor

DISTRICT OF COLUMBIA, Zahra Dorriz

FLORIDA, Michael Shepard, Paul Hiers

GEORGIA, Brent Story, Andy Casey

HAWAII, Julius Fronda

IDAHO, Jesse Barrus

ILLINOIS, Michael Brand

INDIANA, John Wright, Jeff Clanton

IOWA, Michael J. Kennerly, Deanna Maifield, Chris Poole

KANSAS, Scott King

KENTUCKY, Bradley Eldridge, Robert Caudill

LOUISIANA, Chad Winchester, Simone Ardoin, David Smith

MAINE, Brad Foley, Steve Bodge, Charles Hebson

MARYLAND, Jason Ridgway, Eric Marabello, Angela Smith

MASSACHUSETTS, Hasmukh Patel

MICHIGAN, Kristin Schuster MINNESOTA, Chris Roy

MISSISSIPPI, James Pittman, Amy Mood, David Seal

MISSOURI, Eric Schroeter

MONTANA, Lesly Tribelhorn, James Combs

NEBRASKA, Michael Owen

NEVADA, Paul Frost, Kristena Shigenaga

NEW HAMPSHIRE, James Marshall

NEW JERSEY, Richard Jaffe

NEW MEXICO, Gabriela Contreras-Apodaca, Richard Pena

NEW YORK, Richard Lee, Richard Wilder, Stephen Zargham

NORTH CAROLINA, Glenn Mumford, Judith Corley-Lay

NORTH DAKOTA, Roger Weigel

OHIO, David Slatzer

OKLAHOMA, Tim Tegeler

OREGON, David Joe Polly

PENNSYLVANIA, Melissa Batula

PUERTO RICO, Luis Santos, José E. Santana-Pimentel

RHODE ISLAND, Vincent Palumbo

SOUTH CAROLINA, Ladd Gibson, Rob Bedenbaugh,

James Kendall, Jr.

SOUTH DAKOTA, Mark A. Leiferman

TENNESSEE, Jennifer Lloyd, Ali Hangul, Jeff Jones

TEXAS, Mark A. Marek

UTAH, Ben Huot, Fred Doehring, George Lukes

VERMONT, Kevin Marshia, Jesse Devlin, Kenneth Robie

VIRGINIA, Barton A. Thrasher, Robert H. Cary,

Mohammad Mirshahi,

WASHINGTON, Edward Carpenter, Nancy Boyd,

Michael Flemming

WEST VIRGINIA, RJ Scites, Dirar Ahmad, Chad Toney

WISCONSIN, Jerry H. Zogg

WYOMING, Andrea Allen, Sandra Pecenka

ALBERTA, Moh Lali

SASKATCHEWAN, Sukhy Kent

KOREA, Chan-Su “Chris” Reem

TEXAS TRANSPORTATION INSTITUTE, Paul Carlson

VIRGINIA TECH TRANSPORTATION INSTITUTE,

Ronald Gibbons

AASHTO, Marty Vitale, Liaison

Technical committee on Roadside Safety
2016

Keith A. Cota, New Hampshire, Chair

Chris Poole, Iowa, Vice Chair

Nicholas Artimovich, II, FHWA, Secretary

Kelly Hardy, AASHTO Liaison

Representatives from the Subcommittee on Design

Kevin Herritt, California

C. Andy Casey, Georgia

Scott King, Kansas

Jason Siwula, Kentucky

Paul Fossier, Jr., Louisiana

Teri Soos, Maryland

Alexander Bardow, Massachusetts

Michael Elle, Minnesota

Arielle Ehrlich, Minnesota

David Bizuga, New Jersey

Bradley Bortnick, New York

Bucky Galloway, North Carolina

Bernie Clocksin, South Dakota

Christopher Lindsey, Texas

Alex Price, Virginia

Erik Emerson, Wisconsin

William Wilson, Wyoming

Members from the U.S. Department of Transportation

Richard Albin, FHWA

Eduardo Arispe, FHWA

Frank Julian, FHWA

Will Longstreet, FHWA

Associate Member—International

Mark Ayton, Ontario

Associate Member—Other

Mark Bush, TRB

AASHTO

Kevin Sablan, Liaison

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/collection_detail.aspx?ID=34>.

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