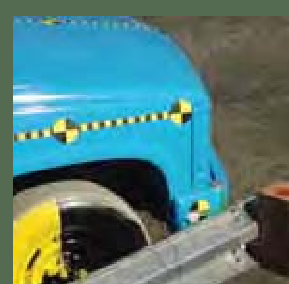
American Association of State Highway
and Transportation Officials

Manual for Assessing Safety Hardware

2009



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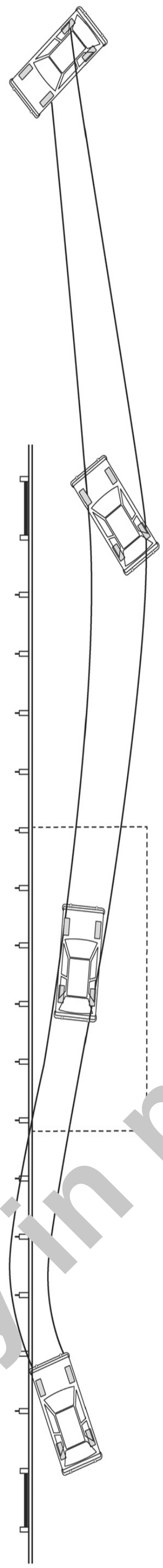

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PREFACE

Effective traffic barrier systems, end treatments, crash cushions, breakaway devices, truck-mounted attenuators, and other hardware are used to achieve the highest levels of highway safety. New systems are continually emerging to address safety problems, and traditional devices and practices for their use are being improved in response to an increased understanding of safety performance, a changing vehicle fleet, the emergence of new materials, and other factors. Full-scale crash testing has been and will continue to be the most common method of evaluating the impact performance of safety hardware. Because many agencies conduct such tests, there is a need for uniformity in the procedures and criteria used to evaluate traffic barriers and other roadside safety features.

Procedures for full-scale vehicle crash testing of guardrails were first published in the Transportation Research Board (TRB) *Highway Research Correlation Services Circular 482* in 1962. This one-page document specified vehicle mass, impact speed, and approach angle for the crash tests. In 1974, the *National Cooperative Highway Research Program (NCHRP) Report 153: Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances* was published to address questions that were not covered in Circular 482. This 16-page document provided a more complete set of testing procedures. *Transportation Research Circular 191*, published in 1978, addressed minor changes needed to address particular problem areas in NCHRP Report 153.

In 1980, *National Cooperative Highway Research Program (NCHRP) Report 230: Recommended Procedures for the Safety Performance Evaluation of Highway Safety Appurtenances* was published to broaden the scope of NCHRP Report 153. This 36-page document incorporated new procedures, updated the evaluation criteria, and brought the procedures up to date with available technology and practices. This document served as the primary reference for full-scale crash testing of highway safety appurtenances in the U.S. and in many other parts of the world.

During the subsequent decade, the evolution of roadside safety concepts, technology, and practices necessitated an update to NCHRP Report 230. Reasons included significant changes in the vehicle fleet, the emergence of new barrier designs, increased interest in matching safety performance to levels of roadway utilization, and advances in computer simulation and other evaluation methods. The resulting document, *National Cooperative Highway Research Program (NCHRP) Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*, was published in 1993.

The AASHTO *Manual for Assessing Safety Hardware* (MASH), 2009, is an update to and supersedes NCHRP Report 350 for the purposes of evaluating new safety hardware devices. This publication marks the first time that AASHTO has officially adopted crash-testing procedures for use in assessing roadside hardware. Previous editions were published as research reports from TRB and NCHRP. In addition, it should be noted that MASH does not supersede any guidelines for the design of roadside safety hardware, which are contained within the AASHTO *Roadside Design Guide*.

MASH was developed through NCHRP Project 22-14(02), "Improvement of Procedures for the Safety-Performance Evaluation of Roadside Features," and contains revised criteria for impact performance evaluation of virtually all highway safety features. Updates to MASH include increases in the size of several test vehicles to better match the current vehicle fleet, changes to the number and impact conditions of the test matrices, and more objective, quantitative evaluation criteria.

An implementation plan for MASH that was adopted jointly by AASHTO and FHWA states that all highway safety hardware accepted prior to the adoption of MASH – using criteria contained in NCHRP Report 350 – may remain in place and may continue to be manufactured and installed. In addition, highway safety hardware accepted using NCHRP Report 350 criteria is not required to be retested using MASH criteria. However, new highway safety hardware not previously evaluated must utilize MASH for testing and evaluation.

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1 Introduction

1.1 PURPOSE AND SCOPE

The purpose of this report 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 accident 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* (119). 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 98th 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 92.5 percentile of real-world crashes. 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 recommend 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 only. 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* (3) 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 (gating/non-gating)
  - Non-redirective (gating)

- 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 barrier may be tested to six test levels and other roadside features are 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 all incorporate some form of heavy truck. Note that longitudinal barrier is the only classification for which all six test levels are defined at this time. All other safety features are designed exclusively for private 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 rural collector or local roads or urban streets. 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, will allow large lateral deflections, and be less likely to redirect the impacting vehicle back into 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 appropriate 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 (50.0) 31 (50.0)	25 25
2	1100C (Passenger Car) 2270P (Pickup Truck)	44 (70.0) 44 (70.0)	25 25
3	1100C (Passenger Car) 2270P (Pickup Truck)	62 (100.0) 62 (100.0)	25 25
4	1100C (Passenger Car) 2270P (Pickup Truck) 10000S (Single-Unit Truck)	62 (100.0) 62 (100.0) 56 (90.0)	25 25 15
5	1100C (Passenger Car) 2270P (Pickup Truck) 36000V (Tractor-Van Trailer)	62 (100.0) 62 (100.0) 50 (80.0)	25 25 15
6	1100C (Passenger Car) 2270P (Pickup Truck) 36000T (Tractor-Tank Trailer)	62 (100.0) 62 (100.0) 50 (80.0)	25 25 15

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

1.6 INTERNATIONAL HARMONIZATION

Concurrent with the preparation of this report, 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 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 REPORT

Chapter 2 outlines the test matrices and conditions recommended for testing and evaluating of 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 documented. Chapter 7 contains guidelines on how in-service performance 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.