

Manual for Assessing Safety Hardware

Second Edition



2016

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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.

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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.

Test Matrices and Conditions



2.1 GENERAL

A limited series of crash tests are recommended to evaluate each class of roadside safety feature. The purpose of this testing is to provide an established minimum level of performance for safety features as well as a basis for comparing different designs within each class. Each of the recommended tests is designed to assess one or more of the three principal evaluation criteria: occupant risk, vehicle trajectory, and structural adequacy. Further, as mentioned previously, the crash testing guidelines cannot include all possible impact conditions that may be experienced in the real world and it is not practical or feasible to test for all possible impact conditions. However, if a significant “window of vulnerability” is identified for any given design, the test matrices should be supplemented to explore the additional impact conditions.

The primary parameters that define a full-scale crash test include impact speed, impact angle, test vehicle mass, and impact location. Each of these parameters is selected to represent a “worst practical condition” for a roadside feature crash. For impact speed and angle, the “worst practical condition” has been traditionally set at the 85th percentile level. Test vehicles are normally selected based upon vehicle body style and weight. Weights have generally been selected to approximate the 2nd and 90th percentile levels for passenger vehicles. Impact locations on a safety feature are often selected to represent a critical impact point (CIP) that creates the greatest probability of test failure. Hence, the combination of 85th percentile impact speed, 85th percentile impact angle, 5th and 95th percentile vehicle weights, and critical impact point is believed to represent a worst practical condition.

Note that many safety features, including guardrail terminals, crash cushions, and truck-mounted attenuators, are designed to accommodate end-on impacts. Crash testing has shown that high-angle, end-on impacts on these features are much less likely to result in serious injury than impacts with lower angles. In keeping with the spirit of the “worst practical condition” philosophy, impact angles for end-on crash tests have been set well below the 85th percentile level.

2.1.1 IMPACT CONDITIONS

The best available information from reconstruction of run-off-the-road passenger vehicle crashes on high-speed roadways (85, 96) indicates that the impact speed of 62 mph (100 km/h) and the impact angle of 25 degrees approximate the 85th percentile of the respective real-world impact conditions. Therefore,

these values were selected to represent the limiting impact conditions for high-speed, high-volume roadways. For lower volume, lower speed facilities, or both, the impact speed was reduced from 62 mph (100 km/h) to 44 mph (70 km/h) or 31 mph (50 km/h), as appropriate. In recognition of the reduced cornering characteristics of large trucks, the impact angles for all large truck tests are reduced to 15 degrees. Impact speeds for single-unit trucks have also been reduced to 56 mph (90 km/h) while those for the heavy tractor-trailer type trucks are reduced to 50 mph (80 km/h) to further compensate for the lower operating speed and reduced cornering capabilities associated with combination vehicles.

Selection of the type, size, and weight of the test vehicles could have a significant bearing on the magnitude of the impact associated with the crash tests. Both small and large passenger vehicles can pose a significant and unique set of challenges for most types of roadside safety hardware. Evaluation of 2002 vehicle sales (159) reveals that weights of all classes of passenger vehicles have risen significantly since these guidelines were last revised (129). In order to minimize the weight increase while maintaining a large enough sales volume to assure ready availability of the test vehicles, the small car test vehicle was selected to be representative of the 2nd percentile heaviest passenger vehicle (instead of the traditional 5th percentile), and the light truck test vehicle was selected to be representative of the 90th percentile (instead of the traditional 95th percentile) heaviest passenger vehicle. The selected test vehicles are a sedan weighing approximately 2,420 lb (1,100 kg) for the small car test vehicle (designation 1100C) and a four-door, two-wheel drive, half-ton pickup truck weighing 5,000 lb (2,270 kg) for the light truck test vehicle (designation 2270P). An alternative test vehicle, designated as 1500A, was also identified for use in evaluating the impact performance of staged energy absorbing systems. The 1500A test vehicle is a four-door passenger sedan weighing approximately 3,300 lb (1,500 kg). Three heavy truck test vehicles—a 22,000-lb (10,000-kg) single-unit truck, an 80,000-lb (36,000-kg) tractor-van-trailer combination, and an 80,000-lb (36,000-kg) tractor-tank-trailer combination—have also been identified for evaluation of higher performance barriers. These vehicles are designated as 10000S, 36000V and 36000T, respectively. Detailed specifications for the test vehicles are presented in Chapter 4.

Impact locations for most full-scale crash tests are selected to represent the critical condition that would be most likely to lead to test failure. For longitudinal barriers, critical impact points (CIPs) are selected to maximize loading at rail splices and maximize the potential for wheel snag and vehicle pocketing. Note that any splice connection expected to be used in the field must be implemented in the critical region during full-scale crash testing. Critical impact points for post-and-beam type barrier terminals and crash cushions are selected to represent the point where the system is believed to transition from gating to redirective behavior. General guidelines for selecting CIP locations for each class of safety feature are described in Section 2.3. Where possible, testing agencies are encouraged to utilize more detailed analysis, such as computer simulation, to estimate the CIP location for each full-scale crash test. Detailed procedures for estimating CIP locations for roadside safety features are presented elsewhere (125) and will not be repeated herein.

2.1.2 TOLERANCES ON IMPACT CONDITIONS

Most testing agencies use vehicular tow and cable guidance systems to propel a vehicle into a test article. Although these propulsion and guidance systems are reasonably accurate, modest variations in impact speed and angle are not uncommon. However, large deviations from target impact conditions can significantly alter the severity of a test. Thus, reasonable limits must be established for both impact speed and angle. Testing agencies have demonstrated an ability to control impact speeds within a range of ± 2.5 mph (4.0 km/h) from the target condition and to obtain actual impact angles within ± 1.5 degrees of the desired value. Therefore, these limits are selected as the maximum tolerance for impact speed and angle. For crash tests with a target speed of 44 mph (70.0 km/h) or more, the actual impact speed should be no less than 2.5 mph (4 km/h) below the desired impact speed. For tests involving vehicle redirection, the impact angle should be no more than 1.5 degrees below the target value. Tolerances for crash tests with a target speed below 31 mph (50.0 km/h) are limited only by vehicle kinetic energy as described in the following paragraphs.

In some circumstances, longitudinal barriers (e.g., flexible cable barriers) may be positioned within sloped medians in order to shield motorists from obstacles and/or prevent cross-median crashes. For these situations, longitudinal barriers should be crash tested and evaluated with the barriers installed in representative sloped median terrain. When barriers are placed on sloped terrain, such as a flexible cable barrier placed within a median ditch, the target impact conditions (i.e., speed and angle) should be referenced to the time when the vehicle reaches the front slope break point (SBP). For most barriers placed on the front slope of depressed median ditches, vehicles will impact barriers with speeds and angles similar to those exhibited at the front SBP, except for minor speed changes attributed to free fall while extended over the front slopes prior to barrier contact and aerodynamic drag. For barriers positioned on the back slope of depressed median ditches, there is an increased likelihood of deviations in vehicle impact speed and angle due to vehicle-ground contact as the vehicle traverses through the ditch prior to barrier contact. For these events, testing laboratories should also document, to the extent possible, actual impact conditions as the vehicle strikes the barrier.

The severity of an impact is normally measured in terms of impact severity (IS) for crash tests involving vehicle redirection, and kinetic energy (KE) for crash tests involving end-on impacts or breakaway devices. IS, as defined in Equation 2-1, has been shown to be a good indicator of the magnitude of loading on a longitudinal barrier.

$$IS = \frac{1}{2} M (V \sin \theta)^2 \quad (\text{Eq. 2-1})$$

Where:

IS	=	impact severity, kip-ft (kJ)
M	=	vehicle mass, lb (kg)
V	=	impact speed, ft/s (m/s)
θ	=	impact angle, degrees

Total vehicle kinetic energy (KE), as defined in Equation 2-2, is considered a better measure of the severity of all head-on or end-on impacts, including tests of breakaway devices, crash cushions, terminals,

and truck-mounted attenuators. Note that KE is also used as the measure of crash severity for oblique impacts on the ends of terminals and crash cushions.

$$KE = \frac{1}{2}MV^2 \quad (\text{Eq. 2-2})$$

Where:

KE = kinetic energy, kip-ft (kJ)

Even when test speeds and impact angles are within the acceptable tolerances, the IS or KE values of a crash test can be unacceptably low. For this reason, an additional limiting condition is applied to the IS and KE values for full-scale crash tests. IS values for tests involving vehicular redirection and KE values for high-speed tests involving end-on impacts must be no more than 8 percent below the target values. For most full-scale crash tests, excessive impact speeds and angles do not improve the likelihood of a successful test. Therefore, excessive speed and angles are not considered to be a cause for failing these tests, provided all impact performance evaluation criteria are met. The exceptions to this general rule are the low-speed tests, i.e., 19-mph (30-km/h) tests for support structures and work-zone traffic control devices, and 31-mph (50-km/h) test for breakaway utility poles. Since these low-speed tests are intended to evaluate the kinetic energy required to activate the breakaway, fracture, or yielding mechanism of the device, it is recommended that the KE value should be no greater than 20 percent above the target value. Tests that do not fall into the acceptable ranges for IS or KE are considered to be invalid and should be repeated. Acceptable ranges for IS and KE values are listed in the crash test description tables in Section 2.2. Note that limiting IS and KE values are calculated based upon the vehicle test inertial mass and exclude the weight of loose ballast or dummies used in the test.

Although test vehicles are selected to have the appropriate mass, it is sometimes impossible to adjust vehicle weight to exactly match target values. Excessive vehicle mass can increase barrier loadings and can sometimes enhance vehicle stability. Similarly, inadequate vehicle mass can reduce barrier loading and possibly decrease vehicle stability. Therefore, upper and lower limits have been established on vehicle gross static mass, as shown in Table 2-1. Note that ballast can be added to increase test vehicle mass and some vehicle components can be removed to decrease mass. Details of vehicle mass adjustment procedures are presented in Chapter 4.

Impact locations are normally selected to maximize the risk of test failure. Obviously, large errors in the impact location can dramatically affect the safety feature performance. Most vehicle guidance systems used in roadside safety testing have limited levels of accuracy. Based on a survey of crash testing laboratories, acceptable variations in target impact location have been established: 12 in. (300 mm) for side impacts and 6 in. (150 mm) for frontal collisions. In other words, the recommended maximum acceptable tolerance for the impact point is ± 12 in. (300 mm), as measured along the face of the barriers, for tests of longitudinal barriers and sides of terminals or crash cushions. Similarly, test vehicles involved in frontal impacts, including tests of crash cushions, terminals, and structural supports, should contact the test article within ± 6 in. (150 mm) of the target impact point as measured along the front of the test vehicle. Recommended impact points for all tests are presented in Section 2.3.

TABLE 2-1. Vehicle Test Inertial Mass Upper and Lower Limits

Test Vehicle Designation and Type	Target Vehicle Weight, lb (kg)	Acceptable Variation, lb (kg)
1100C (Passenger Car)	2,420 (1,100)	±55 (25)
1500A (Passenger Car)	3,300 (1,500)	±220 (100)
2270P (Pickup Truck)	5,000 (2,270)	±110 (50)
10000S (Single-Unit Truck)	22,000 (10,000)	±660 (300)
36000V (Tractor-Van Trailer)	79,300 (36,000)	±1,100 (500)
36000T (Tractor-Tank Trailer)	79,300 (36,000)	±1,100 (500)

2.1.3 SAFETY FEATURE ORIENTATION

Crash test conditions described in this chapter are relative to the alignment of the roadway. Because safety hardware is normally designed to be placed parallel to the roadway, vehicle impact angles relative to tested safety features will normally be the same when measured from the centerline of the tested system. However, some classes of hardware, such as flared guardrail terminals, are designed to be placed at an angle relative to the roadway. Safety features should be tested with the centerline oriented as it normally would be in service. Because impact angles are measured relative to the roadway alignment, actual impact angles measured relative to the system's centerline for flared guardrail terminals and other systems not normally installed parallel to the roadway may be higher or lower than the values shown in the following sections.

2.2 TEST MATRICES

2.2.1 LONGITUDINAL BARRIERS

2.2.1.1 General

All longitudinal barriers, including roadside barriers, bridge rails, median barriers, and temporary barriers, are designed to contain, redirect, and shield vehicles from roadside obstacles. Therefore, the following evaluation guidelines apply to all barrier types. Barrier transition systems must be designed in concert with barrier development. Therefore, as shown in Table 2-2A, full-scale crash testing is recommended for both within the length-of-need (LON) and at the transition between two different barrier types. Note that, when two adjacent barriers have drastically different stiffness, the transition design often incorporates two significant stiffness changes, one from the more flexible barrier to the transition section and the other from the transition section to the more rigid barrier, both of which can produce vehicle rollover, pocketing, or rail rupture (109). In this situation, the user should conduct transition testing at both locations, i.e., upstream of the end of the more flexible barrier and upstream of the more rigid barrier.

Roadside barriers are generally classified according to stiffness into one of three categories: flexible, semi-rigid, and rigid. Although the test matrix is the same for all three classifications of barrier, some consideration should be given to the type of barrier when constructing the test installation. Height variations during construction can adversely affect barrier performance. Increased mounting height is most likely to adversely affect barrier performance for small car impacts while reduced height is considered most likely to affect barrier performance for light truck impacts. Thus, for barrier systems with large allowable variations in mounting heights, small car tests should be conducted with barrier rail elements installed at the maximum acceptable height and light truck tests should be conducted with rail elements at the minimum acceptable height. Refer to Section 3.4.2 for specific installation details of various barriers.

When shielding motorists from roadside or median obstacles, it may be desired or necessary to install longitudinal barriers on roadside or median slopes. For example, it is not uncommon for flexible cable barrier to be placed within a depressed median. In these circumstances, full-scale crash testing should also be performed on barriers installed on or near sloped terrain representative of actual field conditions. Toward this goal, test matrices have been developed for evaluating cable barriers placed in depressed medians, more specifically symmetric V-shaped ditches. Successful testing and evaluation of cable barriers installed in V-ditches should allow for their placement in other less critical ditch configurations, such as stepped medians or flat bottom trapezoidal ditches. It should be noted that these test matrices were developed only for Test Level 3 (TL-3) applications. If a Test Level 4 (TL-4) cable barrier system is desired, it is recommended that any additional crash testing with large single-unit trucks be performed with the cable barrier installed on level or relatively flat terrain. These matrices were primarily developed based on research results obtained from a vehicle trajectory study of simulated small car, mid-size sedan, and light-truck passenger vehicle encroachments into 4H:1V and 6H:1V V-ditches at a speed of 62 mph and at an angle of 25 degrees (95). Further refinement of the test matrices occurred using results from prior crash tests of cable barriers placed in V-ditches and input from roadside safety experts and test laboratories.

For 4H:1V and 6H:1V median ditches, crash test matrices are provided for evaluating: (1) a single cable barrier system placed anywhere within a median ditch; (2) a single cable barrier system placed between 0 to 4 ft beyond the front or back slope break point (SBP); and (3) two cable barrier systems (i.e., double cable barrier) placed within a median ditch, each 0 to 4 ft away from a SBP. For single and double cable barrier systems placed at 0 to 4 ft away from a SBP, the test matrix is a subset of the matrix developed for placement of a cable barrier system anywhere within the ditch. Guidance for determining the appropriate subset of required crash tests is provided below. For cable barriers installed in 4H:1V depressed medians, a 46-ft wide ditch is recommended for the crash testing program. A 30-ft wide ditch is recommended for evaluating cable barriers installed in 6H:1V depressed medians. These widths were determined based on vehicle trajectory and kinematics through the ditch derived from vehicle dynamics simulations and crash testing experience. Further details for crash testing cable barriers installed on slopes or in ditches are provided below. Test matrices for the selected cable barrier-ditch combinations are summarized in Tables 2-2B through 2-2E. Recommended cable barrier placement for testing and evaluating cable barrier systems in 4H:1V and 6H:1V V-ditches is provided in Figures 2-2A and 2-2B, respectively.

2.2.1.2 Description of Tests

These procedures establish a two digit naming system consistent with NCHRP Report 350 (129) for full-scale crash tests. The first digit is used to identify the test level followed by the second digit that identifies the specific test in the series for each type of feature.

TABLE 2-2A. Recommended Test Matrices for Longitudinal Barriers

Test Level	Barrier Section ^c	Test No.	Vehic.	Impact Speed, ^a mph (km/h)	Impact Angle, ^a θ, deg.	Im- pact Point	Acceptable IS Range, ^a kip-ft (kJ)	Evaluation Criteria ^b
1	Length-of-Need	1-10 1-11	1100C 2270P	31 (50.0) 31 (50.0)	25 25	(c) (c)	≥13 (17.4) ≥27 (36.0)	A,D,F,H,I A,D,F,H,I
	Transition	1-20 ^d 1-21	1100C 2270P	31 (50.0) 31 (50.0)	25 25	(c) (c)	≥13 (17.4) ≥27 (36.0)	A,D,F,H,I A,D,F,H,I
2	Length-of-Need	2-10 2-11	1100C 2270P	44 (70.0) 44 (70.0)	25 25	(c) (c)	≥25 (34.2) ≥52 (70.5)	A,D,F,H,I A,D,F,H,I
	Transition	2-20 ^d 2-21	1100C 2270P	44 (70.0) 44 (70.0)	25 25	(c) (c)	≥25 (34.2) ≥52 (70.5)	A,D,F,H,I A,D,F,H,I
3	Length-of-Need	3-10 3-11	1100C 2270P	62 (100.0) 62 (100.0)	25 25	(c) (c)	≥51 (69.7) ≥106 (144)	A,D,F,H,I A,D,F,H,I
	Transition	3-20 ^d 3-21	1100C 2270P	62 (100.0) 62 (100.0)	25 25	(c) (c)	≥51 (69.7) ≥106 (144)	A,D,F,H,I A,D,F,H,I
4	Length-of-Need	4-10	1100C	62 (100.0)	25	(c)	≥51 (69.7)	A,D,F,H,I
		4-11	2270P	62 (100.0)	25	(c)	≥106 (144)	A,D,F,H,I
		4-12	10000S	56 (90.0)	15	(c)	≥142 (193)	A,D,G
	Transition	4-20 ^d 4-21 4-22	1100C 2270P 10000S	62 (100.0) 62 (100.0) 56 (90.0)	25 25 15	(c) (c) (c)	≥51 (69.7) ≥106 (144) ≥142 (193)	A,D,F,H,I A,D,F,H,I A,D,G
5	Length-of-Need	5-10	1100C	62 (100.0)	25	(c)	≥51 (69.7)	A,D,F,H,I
		5-11	2270P	62 (100.0)	25	(c)	≥106 (144)	A,D,F,H,I
		5-12	36000V	50 (80.0)	15	(c)	≥404 (548)	A,D,G
	Transition	5-20 ^d 5-21 5-22	1100C 2270P 36000V	62 (100.0) 62 (100.0) 50 (80.0)	25 25 15	(c) (c) (c)	≥51 (69.7) ≥106 (144) ≥404 (548)	A,D,F,H,I A,D,F,H,I A,D,G
6	Length-of-Need	6-10	1100C	62 (100.0)	25	(c)	≥51 (69.7)	A,D,F,H,I
		6-11	2270P	62 (100.0)	25	(c)	≥106 (144)	A,D,F,H,I
		6-12	36000T	50 (80.0)	15	(c)	≥404 (548)	A,D,G
	Transition	6-20 ^d 6-21 6-22	1100C 2270P 36000T	62 (100.0) 62 (100.0) 50 (80.0)	25 25 15	(c) (c) (c)	≥51 (69.7) ≥106 (144) ≥404 (548)	A,D,F,H,I A,D,F,H,I A,D,G

^a See Section 2.1.2 for tolerances on impact conditions.

^b See Table 5-1.

^c See Figure 2-1 and Section 2.3.2 for impact point.

^d Test is optional.

TABLE 2-2B. Recommended TL-3 Test Matrix for Single Cable Median Barrier Designed for Placement Anywhere in 4H:1V V-Ditch

Test Desig. No.	Veh. Type	Impact Conditions		V-Ditch Width (ft)	Barrier Position	Barrier Location ^a	Critical Impact Point	Acceptable IS Range, ^b kip-ft (kJ)	Eval. Criteria ^c
		Speed, mph (km/h)	Angle (deg)						
3-10	1100C	62 (100)	25	NA ^d	Level Terrain	NA ^d	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-11	2270P	62 (100)	25	NA ^d	Level Terrain	NA ^d	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-13	2270P	62 (100)	25	46	Front Slope	12 ft from Front SBP ^e	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-14	1100C	62 (100)	25	46	Front Slope	12 ft from Front SBP ^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-15	1100C	62 (100)	25	46	Back Slope	4 ft from Ditch Bottom	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-16	1100C	62 (100)	25	46	Back Slope	4 ft from Back SBP ^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-17	1500A	62 (100)	25	46	Front Slope	Variable ^f	Midspan Location	≥70 (95.1)	A,D,F,H,I
3-18	2270P	62 (100)	25	46	Back Slope	8 ft from Back SBP ^e	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I

a See Figure 2-2A for barrier placement.

b See Section 2.1.2 for tolerances on impact conditions.

c See Table 5-1.

d Not applicable.

e Slope break point.

f Testing laboratory should determine critical barrier position on front slope of ditch in order to maximize propensity for front end of 1500A vehicle to penetrate between vertically adjacent cables. Critical factors may include vertical cable spacing, position of cables relative to front bumper, location and type of cable release mechanisms, trajectory of vehicle's front bumper, etc.

TABLE 2-2C. Recommended TL-3 Test Matrix for Single or Double Cable Median Barrier Designed for Placement between 0 to 4-ft Offset from Slope Break Point of 4H:1V V-Ditch

Test Desig. No.	Veh. Type	Impact Conditions		V-Ditch Width (ft)	Barrier Posi- tion	Barrier Loca- tion ^a	Critical Impact Point	Accept- able IS Range, ^b kip-ft (kJ)	Eval. Criteria ^c
		Speed, mph (km/h)	Angle (deg)						
3-10	1100C	62 (100)	25	NA ^d	Level Terrain	NA	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-11	2270P	62 (100)	25	NA ^d	Level Terrain	NA	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-13	2270P	62 (100)	25	46	Front Slope	4 ft from Front SBP ^e	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-14	1100C	62 (100)	25	46	Front Slope	4 ft from Front SBP ^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-15 ^{f,g}	1100C	62 (100)	25	46	Back Slope	4 ft from Ditch Bottom	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-16 ^g	1100C	62 (100)	25	46	Back Slope	4 ft from Back SBP ^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-17	1500A	62 (100)	25	46	Front Slope	Vari- able ^h	Midspan Location	≥70 (95.1)	A,D,F,H,I
3-18 ^g	2270P	62 (100)	25	46	Back Slope	8 ft from Back SBP ⁱ	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I

a See Figure 2-2A for barrier placement.

b See Section 2.1.2 for tolerances on impact conditions.

c See Table 5-1.

d Not applicable.

e Slope break point.

f Test no. 15 is unnecessary for V-ditches greater than or equal to 26 ft, as measured from front SBP to back SBP.

g Test nos. 15, 16, and 18 are unnecessary for double median barrier system placed within median ditch, one on each side and 0 to 4 ft from a SBP.

h Testing laboratory should determine critical barrier position from 0 to 4 ft on front slope of ditch in order to maximize propensity for front end of 1500A vehicle to penetrate between adjacent vertical cables. Critical factors may include vertical cable spacing, position of cables relative to front bumper, location and type of cable release mechanisms, trajectory of vehicle's front bumper, etc.

i A 46-ft wide ditch was selected to simplify the test matrix, thus resulting in barrier placement beyond the 0 to 4 ft range. However, narrower ditch widths provided similar risks for override with a barrier placed at the back SBP.

TABLE 2-2D. Recommended TL-3 Test Matrix for Single Cable Median Barrier Designed for Placement Anywhere in 6H:1V V-Ditch

Test Desig. No.	Veh. Type	Impact Conditions		V-Ditch Width (ft)	Barrier Posi- tion	Barrier Loca- tion ^a	Critical Impact Point	Accept- able IS Range, ^b kip-ft (kJ)	Eval. Criteria ^c
		Speed, mph (km/h)	Angle (deg)						
3-10	1100C	62 (100)	25	NA ^d	Level Terrain	NA ^d	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-11	2270P	62 (100)	25	NA ^d	Level Terrain	NA ^d	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-13	2270P	62 (100)	25	30	Front Slope	9 ft from Front SBP ^e	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-14	1100C	62 (100)	25	30	Front Slope	9 ft from Front SBP ^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-15 ^{f,g}	1100C	62 (100)	25	30	Back Slope	4 ft from Ditch Bottom	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-16 ^g	1100C	62 (100)	25	30	Back Slope	1 ft from Back SBP ^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-17	1500A	62 (100)	25	30	Front Slope	Variable ^f	Midspan Location	≥70 (95.1)	A,D,F,H,I
3-18 ^g	2270P	62 (100)	25	30	Back Slope	Back SBP ^e	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I

a See Figure 2-2B for barrier placement.

b See Section 2.1.2 for tolerances on impact conditions.

c See Table 5-1.

d Not applicable.

e Slope break point.

f Testing laboratory should determine critical barrier position from 0 to 4 ft on front slope of ditch in order to maximize propensity for front end of 1500A vehicle to penetrate between adjacent vertical cables. Critical factors may include vertical cable spacing, position of cables relative to front bumper, location and type of cable release mechanisms, trajectory of vehicle's front bumper, etc.

TABLE 2-2E. Recommended TL-3 Test Matrix for Single or Double Cable Median Barrier Designed for Placement between 0 to 4-ft Offset from Slope Break Point of 6H:1V V-Ditch

Test Desig. No.	Veh. Type	Impact Conditions		V-Ditch Width (ft)	Barrier Posi- tion	Barrier Loca- tion ^a	Critical Impact Point	Accept- able IS Range, ^b kip-ft (kJ)	Eval. Criteria ^c
		Speed, mph (km/h)	Angle (deg)						
3-10	1100C	62 (100)	25	NA ^d	Level Terrain	NA ^d	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-11	2270P	62 (100)	25	NA ^d	Level Terrain	NA ^d	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-13	2270P	62 (100)	25	30	Front Slope	4 ft from Front SBP^e	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I
3-14	1100C	62 (100)	25	30	Front Slope	4 ft from Front SBP^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-15 ^{f,g}	1100C	62 (100)	25	30	Back Slope	4 ft from Ditch Bottom	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-16 ^g	1100C	62 (100)	25	30	Back Slope	1 ft from Back SBP ^e	Midspan Location	≥51 (69.7)	A,D,F,H,I
3-17	1500A	62 (100)	25	30	Front Slope	Variable ^f	Midspan Location	≥70 (95.1)	A,D,F,H,I
3-18 ^g	2270P	62 (100)	25	30	Back Slope	Back SBP ^e	1 ft Upstream from Post	≥106 (144)	A,D,F,H,I

a See Figure 2-2B for barrier placement.

b See Section 2.1.2 for tolerances on impact conditions.

c See Table 5-1.

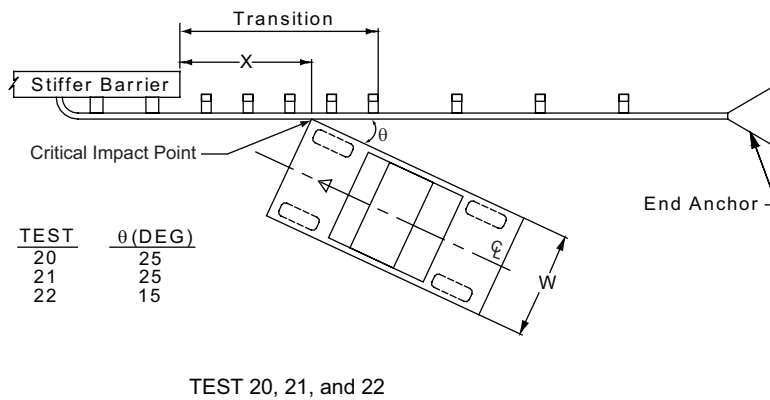
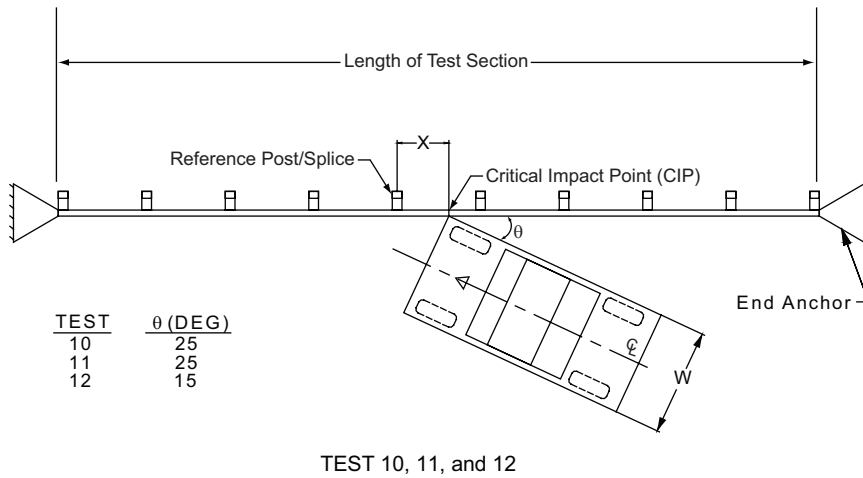
d Not applicable.

e Slope break point.

f Test no. 15 is unnecessary for V-ditches greater than or equal to 24 ft, as measured from front SBP to back SBP.

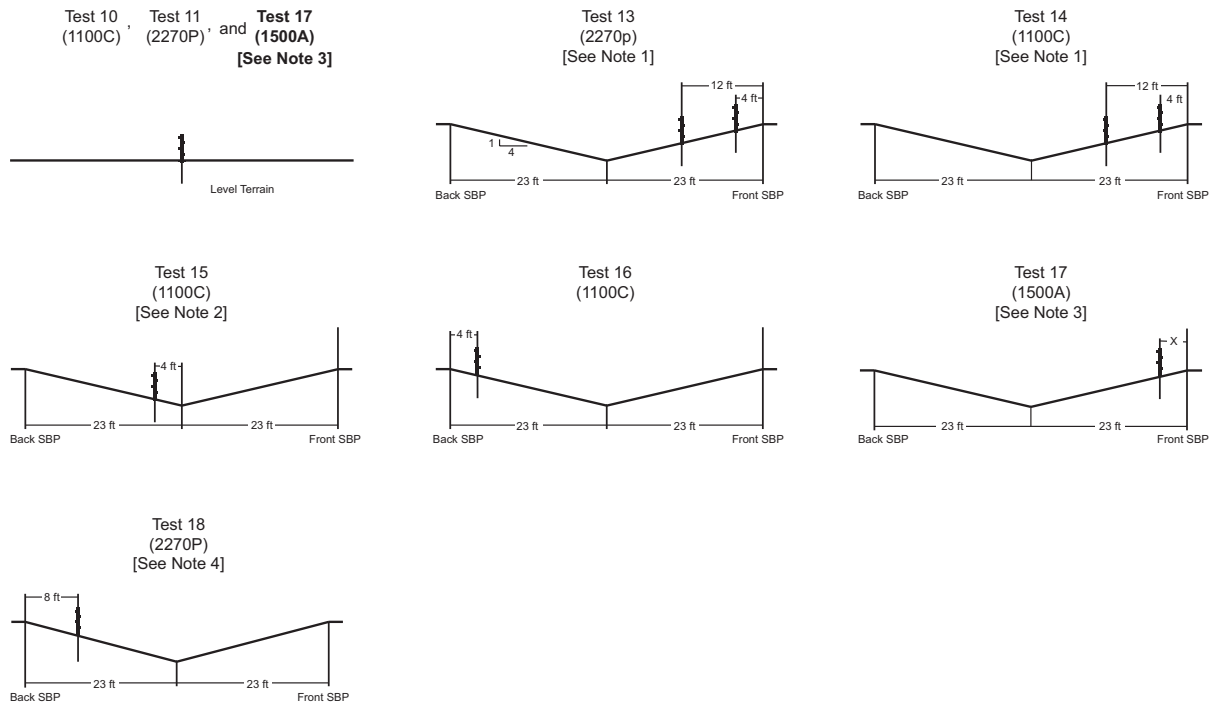
g Test nos. 15, 16, and 18 are unnecessary for double median barrier system placed within median ditch, one on each side and 0 to 4 ft from a SBP.

h Testing laboratory should determine critical barrier position from 0 to 4 ft on front slope of ditch in order to maximize propensity for front end of 1500A vehicle to penetrate between adjacent vertical cables. Critical factors may include vertical cable spacing, position of cables relative to front bumper, location and type of cable release mechanisms, trajectory of vehicle's front bumper, etc.



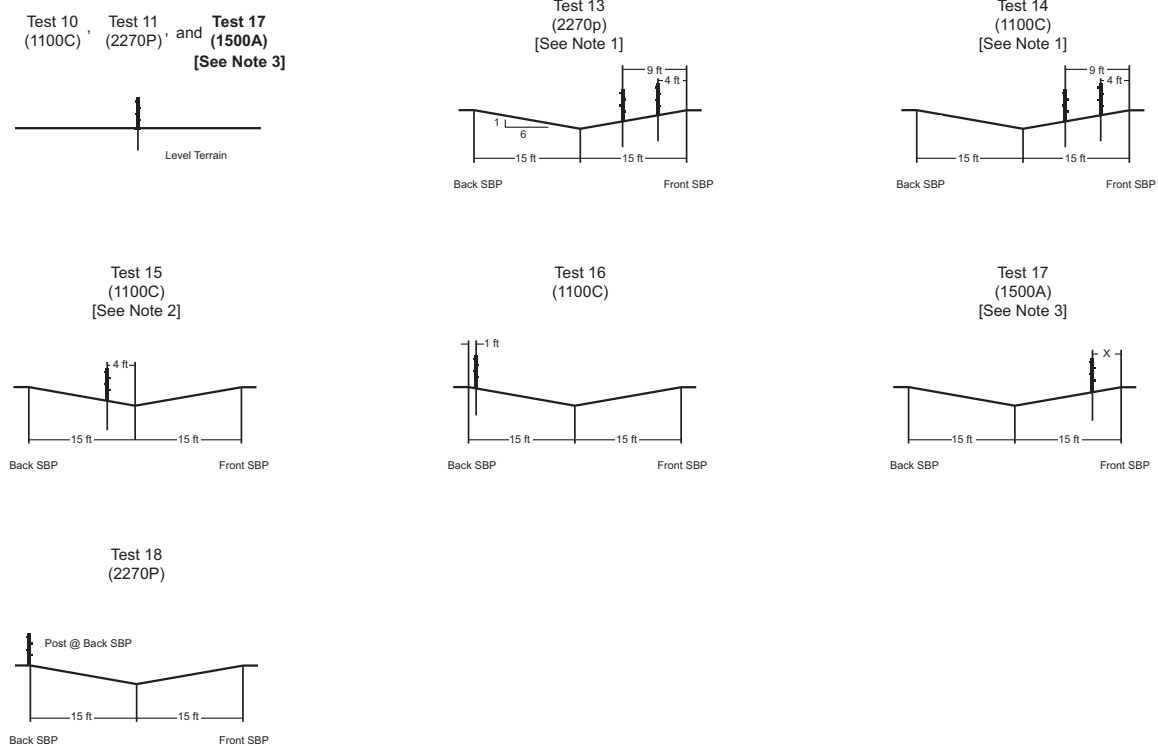
- NOTES:
1. See Section 2.3.2 for determination of "X."
 2. Recommended tolerance on "X" is ± 30 cm.
 3. See Section 2.3.2 for recommendations on impact point for work zone barriers.

Figure 2-1. Impact Conditions for Longitudinal Barrier Tests



- NOTES:
1. For barrier placement anywhere, use a 12-ft lateral offset. Otherwise, use a 4-ft lateral offset for barrier placement within 0 to 4 ft on front SBP.
 2. For single or double median barrier placement at 0 to 4 ft offset from SBP, Test No. 15 is unnecessary for V-ditches greater than or equal to 26 ft, as measured from front SBP to back SBP.
 3. Testing laboratory should determine critical barrier position from 0 to "X" on front slope of ditch or on level terrain in order to maximize the propensity for the front end of 1500A vehicle to penetrate between vertically adjacent cables. Critical factors may include vertical cable spacing, position of cables relative to front bumper, location and type of cable release mechanisms, trajectory of vehicle's front bumper, etc.

Figure 2-2A. Critical Cable Barrier Placement for 4H:1V V-Ditch



- NOTES:
1. For barrier placement anywhere, use a 9-ft lateral offset. Otherwise, use a 4-ft lateral offset for barrier placement within 0 to 4 ft on front SBP.
 2. For single or double median barrier placement at 0 to 4 ft offset from SBP, Test No. 15 is unnecessary for V-ditches greater than or equal to 24 ft, as measured from front SBP to back SBP.
 3. Testing laboratory should determine critical barrier position from 0 to "X" on front slope of ditch or on level terrain in order to maximize the propensity for the front end of 1500A vehicle to penetrate between vertically adjacent cables. Critical factors may include vertical cable spacing, position of cables relative to front bumper, location and type of cable release mechanisms, trajectory of vehicle's front bumper, etc.

Figure 2-2B. Critical Cable Barrier Placement for 6H:1V V-Ditch

TEST 10

Test 10 is designed to investigate a barrier's ability to successfully contain and redirect small passenger vehicles impacting within the length-of-need. For small cars, the primary concerns are the potential for vehicle under-ride, wheel snag, rollover, and head-slap. For flexible cable barriers, additional concerns include cable interaction with and damage to the A-pillar, windshield, and roof. In order to evaluate the full range of barrier impact performance, testing agencies should consider installing the barrier at the maximum allowable height for small car tests. This is especially true for post-and-beam barrier systems to maximize the risk of under-ride and wheel snag.

TESTS 11 and 21

Tests 11 and 21 provide maximum strength tests for Test Levels 1 through 3 and verify a barrier's performance for impacts involving light trucks and SUVs for all test levels. Due to the high rollover frequencies observed in crash data and during historical full-scale crash testing with light truck vehicles, Tests 11 and 21 are required for all barrier systems. For flexible cable barriers, the primary concerns include vehicle containment, vehicle stability, A-pillar integrity, and working width. These tests are now required to also meet all occupant risk measures, including both lateral and longitudinal occupant impact velocity (OIV) and ridedown acceleration (RA) values.

TEST 20 (Optional)

Test 20 for a transition section is an optional test to evaluate the occupant risk and post-impact trajectory criteria for all test levels. It should be conducted if there is reasonable uncertainty regarding the impact performance of the system for impacts with small passenger vehicles.

TESTS 12 and 22

Tests 12 and 22 are conducted for Test Levels 4, 5, and 6. These tests are intended to evaluate the strength of the barrier in containing and redirecting heavy trucks.

TEST 13

Test 13 is designed to assess a cable barrier's ability to contain and redirect light trucks and SUVs as well as prevent barrier override within the length-of-need when placed on a roadside slope or front slope of a median ditch. The 2270P vehicle provides a critical test due to its large mass moment of inertia, high center of mass, and high bumper trajectory relative to the ditch ground surface. For cable barriers designed to be installed anywhere in a median ditch, the cable barrier shall be placed 12 and 9 ft away from the front SBP of a 46-ft wide 4H:1V V-ditch and a 30-ft wide 6H:1V V-ditch, respectively. For cable barriers intended for use between 0 to 4 ft away from the slope break point, the barrier shall be placed 4 ft away from the front SBP of the 4H:1V or 6H:1V V-ditch.

TEST 14

The primary objective for Test 14 is to assess a cable barrier's ability to safely contain and redirect small passenger vehicles without resulting in excessive vehicular instabilities and/or rollover when installed on a roadside slope or front slope of a median ditch. The risk for rollover may be aggravated by several factors, including: (1) roll and pitch rotations induced into the airborne vehicle prior to contacting the cable barrier; and (2) instabilities resulting from vehicle contact with the cable barrier while airborne. For cable barriers installed anywhere in a median ditch, the barrier shall be placed 12 and 9 ft away from the front SBP of a 4H:1V and a 6H:1V V-ditch, respectively. For cable barriers intended for use between 0 to 4 ft away from the slope break point, the barrier shall be placed 4 ft away from the front SBP of the 4H:1V or 6H:1V V-ditch.

TEST 15

Test 15 is designed to assess a cable barrier's ability to safely contain and redirect small passenger vehicles as well as prevent barrier underride, component penetration into the occupant compartment, and excessive deformations of the A-pillar, roof, or windshield. For cable barriers installed anywhere in a median ditch, the barrier shall be placed 4 ft up the back slope from the bottom of the 4H:1V or 6H:1V

ditch. For cable barriers intended for use between 0 to 4 ft away from the slope break point, Test 15 is not required for 4H:1V and 6H:1V V ditches greater than or equal to 26 and 24 ft wide, respectively, as measured from front SBP to back SBP. If Test 15 is required for cable barriers intended for use between 0 to 4 ft away from the slope break point due to the likelihood of installation within narrow V-ditches, it is recommended that testing be performed using the placement guidelines provided for barriers installed anywhere within a median ditch. Further, Test 15 is not required for evaluating a double cable barrier system that has one barrier placed on each side of a median ditch, each from 0 to 4 ft away from a SBP.

TEST 16

Test 16 is designed to assess a cable barrier's ability to safely contain and redirect small passenger vehicles after traveling across the center of a ditch and up the back slope. In previous full-scale crash tests of cable barrier systems placed on the backslope of a V-ditch, small passenger vehicles have shown tendencies to either achieve an increased impact angle, acquire a yaw velocity, or rebound off of the ditch surface and become airborne. These vehicle behaviors may lead to an increased propensity for occupant compartment deformation and penetration, vehicular instability, rollover, and/or barrier override. For 4H:1V V-ditches, the cable barrier shall be placed 4 ft away from the back SBP for both a barrier designed for placement anywhere in the ditch or intended for use between 0 to 4 ft from the SBP. For 6H:1V V-ditches, the cable barrier shall be placed 1 ft away from the back SBP for both a barrier designed for placement anywhere in the ditch or intended for use between 0 to 4 ft from the SBP. Test 16 is not required for evaluating a double cable barrier system designed to have a separate cable barrier installation on each side of the ditch placed from 0 to 4 ft away from each SBP.

TEST 17

Test 17 is designed to evaluate a cable barrier's ability to contain and redirect mid-size passenger sedans by preventing vehicle penetration through vertically adjacent cables. Although vehicle penetration through the barrier is the primary concern, this test also assesses risk associated with component penetration into the occupant compartment and excessive deformations to the A-pillar, windshield, or roof. For Test 17 and as determined by the testing laboratory, the critical barrier placement will occur on the front slope and range between 0 ft (i.e., front SBP) and some lateral offset away from the front SBP. **For cable barriers installed on mostly level terrain or adjacent to steep roadside slopes (i.e., steeper than 3H:1V), Test 17 evaluates the risk for passenger vehicles to penetrate between cables depending on barrier configuration (i.e., cable spacing, cable heights, etc.).** Critical barrier placement will consider vehicle and barrier geometries and maximize the propensity for the front end of the 1500A vehicle to penetrate between adjacent cables. The objective is to position the front bumper between the adjacent cables with the widest vertical cable spacing at time of impact. If multiple cable spacings have a similar maximum vertical spacing, the lowest of this group should be targeted to maximize the number of cables potentially in contact with the A-pillar, windshield, and roof during redirection.

TEST 18

Test 18 is designed to assess a cable barrier's ability to safely contain and redirect light trucks and SUVs after traveling across the center of a ditch and up the back slope. In previous full-scale crash tests of cable barrier systems placed on the backslope of a V-ditch, passenger vehicles have shown

tendencies to either achieve an increased impact angle, acquire a yaw velocity, or rebound off of the ditch surface and become airborne. These vehicle behaviors can lead to an increased propensity for vehicular instability, rollover, and/or barrier override. For 4H:1V V-ditches, the cable barrier shall be placed 8 ft away from the back SBP for both a barrier designed for placement anywhere in the ditch or intended for use between 0 to 4 ft from the SBP. For 6H:1V V-ditches, the cable barrier shall be placed at the back SBP for both a barrier designed for placement anywhere in the ditch or intended for use between 0 to 4 ft from the SBP. Test 18 is not required for evaluating a double cable barrier system designed to have a separate cable barrier installation on each side of the ditch placed from 0 to 4 ft away from each SBP.

Figure 2-1 displays impact conditions for Tests 10, 11, 12, 20, 21, and 22. As shown in this figure, critical impact points are measured from a potential snag or fracture location as well as to maximize the propensity for underride, override, or penetration of flexible barriers such as cable barriers installed on a roadside slope or in a median ditch. In some cases, such as transition systems discussed previously, a barrier may have two or more critical impact locations. In this situation, testing agencies should consider testing each of the locations to verify acceptable barrier performance. Critical impact locations for each class of safety feature are defined in Section 2.3.

2.2.2 TERMINALS AND CRASH CUSHIONS

2.2.2.1 General

Terminals and redirective crash cushions fulfill very similar functions. Terminals are designed to reduce the severity of impacts with the end of a longitudinal barrier and function as a redirective barrier when struck along the side. Similarly, redirective crash cushions are designed to reduce the severity of head-on impacts with a fixed object and function as a longitudinal barrier during impacts on the side of the device. However, even though terminals and redirective crash cushions are placed in the same testing category and subjected to the same set of full-scale crash tests, there are some differences in the evaluation criteria that user agencies should consider.

These differences arise primarily due to the classification of crash cushions as either gating or non-gating. Gating crash cushions are designed to allow vehicles impacting near the beginning or nose of the system to safely pass through the unit and travel behind the cushion. Non-gating crash cushions are designed to capture almost all vehicles striking the end of the device and safely decelerate them to a stop. A non-gating crash cushion must capture impacting vehicles during angular tests on the end of the system.

Non-redirective crash cushions are designed to safely accommodate most vehicles striking the front of the cushion, but have no capability to redirect vehicles impacting near the rear of the device. As a result, most non-redirective cushions are designed to be wider than the hazard to be shielded and are typically used farther from traffic where the risk of high-energy impacts near the rear of the cushion is lower. It is the responsibility of user agencies to determine where safety features addressed in this document have application, including redirective and non-redirective crash cushions.

Impact attenuating traffic gates, referred to as resistance gates, are beginning to be placed in front of drawbridges, at-grade railroad crossings, or other locations where penetration of the gate could lead

to a high risk of a severe crash. Because they are designed to attenuate head-on impacts and have no redirective capacity, resistance gates are considered a subset of non-redirective crash cushions. Resistance gate systems are designed to block the wide areas at locations where they are deployed. As a result, most impacts involve vehicles striking the gate at angles near 90 degrees. Minor reductions in the impact angle from 90 to 75 degrees are not believed to increase the likelihood of test failure. Hence, impact attenuating gates are not subjected to low-angle, head-on tests included in the non-redirective crash cushion test matrix. Further, impact attenuating gates cannot be struck along the side of the system and, thus, the crash test along the side of non-redirective crash cushions is also waived. Therefore, impact attenuating gates need only be subjected to Tests 40 and 41. Existing designs are believed to have only one attenuation stage and therefore Test 45 should not normally be necessary. Further, the impact point for all of tests is recommended to be at the quarter point along the face of the system. This impact point should explore asymmetric loading of the attenuation system and be representative of typical impact conditions for a two-lane gate design.

Some longitudinal barriers, such as flexible cable barriers or concrete median barriers, may be installed on roadside fill slopes or within median ditches. However, termination of these systems typically occurs on generally flat terrain. Consequently, the crash testing and evaluation of end treatments for these systems, such as crash cushions and guardrail end terminals, shall continue to be performed with those systems installed on flat, level terrain unless new information suggests procedural changes are in order to be more representative of actual field conditions.

Recommended tests for evaluating the impact performance of terminals and crash cushions are presented in Table 2-3. Impact conditions are presented in Figure 2-3A for terminals and redirective crash cushions and Figure 2-3B for non-redirective crash cushions. These guidelines are applicable to both permanent features and temporary features used in work or construction zones. Reference should be made to the Glossary for definitions of these features.

TABLE 2-3. Recommended Test Matrices for Terminals and Crash Cushions

Test Level	Feature	Feature Type ^a	Test No.	Vehicle	Impact Speed, ^b mph (km/h)	Impact Angle, ^b θ, deg.	Impact Tolerances		Impact Point	Evaluation Criteria ^c	
							Measure ^d	Acc. Range, kip-ft (kJ)		Gating	Non-Gating
1	Terminals and Redirective Crash Cushions	G/NG	1-30	1100C	31 (50.0)	0	KE	≥72 (97.4)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	1-31	2270P	31 (50.0)	0	KE	≥148 (202.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	1-32	1100C	31 (50.0)	5–15	KE	≥72 (97.4)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	1-33	2270P	31 (50.0)	5–15	KE	≥148 (202.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	1-34	1100C	31 (50.0)	15	IS	≥5 (6.5)	(e,g)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	1-35	2270P	31 (50.0)	25	IS	≥27 (36.0)	(e)	A,D,F,H,I	A,D,F,H,I
		G/NG	1-36	2270P	31 (50.0)	25	IS	≥27 (36.0)	(e,g)	A,D,F,H,I	A,D,F,H,I
		G/NG	1-37a	2270P	31 (50.0)	25	IS	≥27 (36.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
			1-37b	1100C				≥13 (17.4)			
		G/NG	1-38	1500A	31 (50.0)	0	KE	≥98 (133.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
	Non-redirective Crash Cushions	G	1-40	1100C	31 (50.0)	0	KE	≥72 (98)	(f)	C,D,F,H,I,N	
		G	1-41	2270P	31 (50.0)	0	KE	≥149 (201)	(f)	C,D,F,H,I,N	
		G	1-42	1100C	31 (50.0)	5–15	KE	≥72 (98)	(f)	C,D,F,H,I,N	
		G	1-43	2270P	31 (50.0)	5–15	KE	≥149 (201)	(f)	C,D,F,H,I,N	
		G	1-44	2270P	31 (50.0)	20	KE	≥149 (201)	(f)	C,D,F,N	
		G	1-45	1500A	31 (50.0)	0	KE	≥98 (133)	(f)	C,D,F,H,I,N	

a G/NG—Test applicable to gating and non-gating devices. G—Test applicable to gating devices.

b See Section 2.1.2 for tolerances on impact conditions.

c See Table 5-1.

d See Equations 2-1 and 2-2.

e See Figure 2-3A for impact point.

f See Figure 2-3B for impact point.

g See Section 2.3.3 for impact point.

TABLE 2-3. Recommended Test Matrices for Terminals and Crash Cushions (continued)

Test Level	Feature	Feature Type ^a	Test No.	Vehicle	Impact Speed, ^b mph (km/h)	Impact Angle, ^b θ, deg.	Impact Tolerances		Impact Point	Evaluation Criteria ^c	
							Mea- sure ^d	Acc. Range, kip-ft (kJ)		Gating	Non-Gating
2	Terminals and Redirective Crash Cushions	G/NG	2-30	1100C	44 (70.0)	0	KE	≥141 (191.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	2-31	2270P	44 (70.0)	0	KE	≥291 (395.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	2-32	1100C	44 (70.0)	5–15	KE	≥141 (191.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	2-33	2270P	44 (70.0)	5–15	KE	≥291 (395.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	2-34	1100C	44 (70.0)	15	IS	≥9 (12.8)	(e,g)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	2-35	2270P	44 (70.0)	25	IS	≥52 (70.5)	(e)	A,D,F,H,I	A,D,F,H,I
		G/NG	2-36	2270P	44 (70.0)	25	IS	≥52 (70.5)	(e,g)	A,D,F,H,I	A,D,F,H,I
		G/NG	2-37a	2270P	44 (70.0)	25	IS	≥52 (70.5)	(e)	C,D,F,H,I,N	A,D,F,H,I
			2-37b	1100C				≥25 (34.2)			
		G/NG	2-38	1500A	44 (70.0)	0	KE	≥192 (261.0)	(e)	C,D,F,H,I,N	A,D,F,H,I
	Non-redirective Crash Cushions	G	2-40	1100C	44 (70.0)	0	KE	≥141 (191)	(f)	C,D,F,H,I,N	
		G	2-41	2270P	44 (70.0)	0	KE	≥291 (395)	(f)	C,D,F,H,I,N	
		G	2-42	1100C	44 (70.0)	5–15	KE	≥141 (191)	(f)	C,D,F,H,I,N	
		G	2-43	2270P	44 (70.0)	5–15	KE	≥291 (395)	(f)	C,D,F,H,I,N	
		G	2-44	2270P	44 (70.0)	20	KE	≥291 (395)	(f)	C,D,F,N	
		G	2-45	1500A	44 (70.0)	0	KE	≥192 (261)	(f)	C,D,F,H,I,N	

a G/NG—Test applicable to gating and non-gating devices. G—Test applicable to gating devices.

b See Section 2.1.2 for tolerances on impact conditions.

c See Table 5-1.

d See Equations 2-1 and 2-2.

e See Figure 2-3A for impact point.

f See Figure 2-3B for impact point.

g See Section 2.3.3 for impact point.

TABLE 2-3. Recommended Test Matrices for Terminals and Crash Cushions (continued)

Test Level	Feature	Feature Type ^a	Test No.	Vehicle	Impact Speed, ^b mph (km/h)	Impact Angle, ^b θ, deg.	Impact Tolerances		Impact Point	Evaluation Criteria ^c	
							Mea- sure ^d	Acc. Range, kip-ft (kJ)		Gating	Non-Gating
3	Terminals and Re-directive Crash Cushions	G/NG	3-30	1100C	62 (100.0)	0	KE	≥288 (390)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	3-31	2270P	62 (100.0)	0	KE	≥594 (806)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	3-32	1100C	62 (100.0)	5–15	KE	≥288 (390)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	3-33	2270P	62 (100.0)	5–15	KE	≥594 (806)	(e)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	3-34	1100C	62 (100.0)	15	IS	≥19 (26)	(e,g)	C,D,F,H,I,N	A,D,F,H,I
		G/NG	3-35	2270P	62 (100.0)	25	IS	≥106 (144)	(e)	A,D,F,H,I	A,D,F,H,I
		G/NG	3-36	2270P	62 (100.0)	25	IS	≥106 (144)	(e,g)	A,D,F,H,I	A,D,F,H,I
		G/NG	3-37a	2270P	62 (100.0)	25	IS	≥106 (144)	(e)	C,D,F,H,I,N	A,D,F,H,I
			3-37b	1100C				≥51 (69.7)			
		G/NG	3-38	1500A	62 (100.0)	0	KE	≥392 (532)	(e)	C,D,F,H,I,N	A,D,F,H,I
	Non-re-directive Crash Cushions	G	3-40	1100C	62 (100.0)	0	KE	≥288 (390)	(f)	C,D,F,H,I,N	
		G	3-41	2270P	62 (100.0)	0	KE	≥594 (806)	(f)	C,D,F,H,I,N	
		G	3-42	1100C	62 (100.0)	5–15	KE	≥288 (390)	(f)	C,D,F,H,I,N	
		G	3-43	2270P	62 (100.0)	5–15	KE	≥594 (806)	(f)	C,D,F,H,I,N	
		G	3-44	2270P	62 (100.0)	20	KE	≥594 (806)	(f)	C,D,F,N	
		G	3-45	1500A	62 (100.0)	0	KE	≥393 (532)	(f)	C,D,F,H,I,N	

a G/NG—Test applicable to gating and non-gating devices. G—Test applicable to gating devices.

b See Section 2.1.2 for tolerances on impact conditions.

c See Table 5-1.

d See Equations 2-1 and 2-2.

e See Figure 2-3A for impact point.

f See Figure 2-3B for impact point.

g See Section 2.3.3 for impact point.

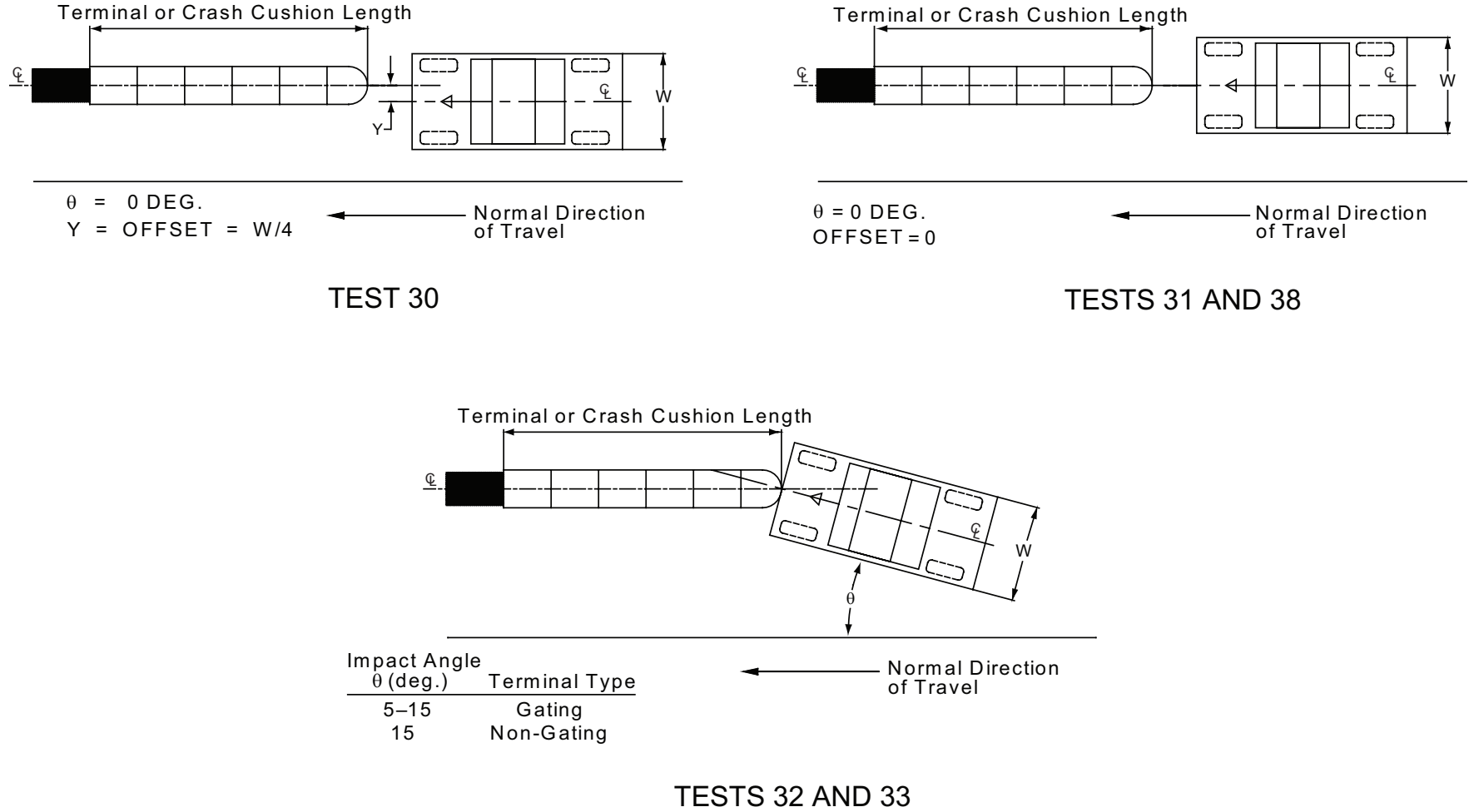
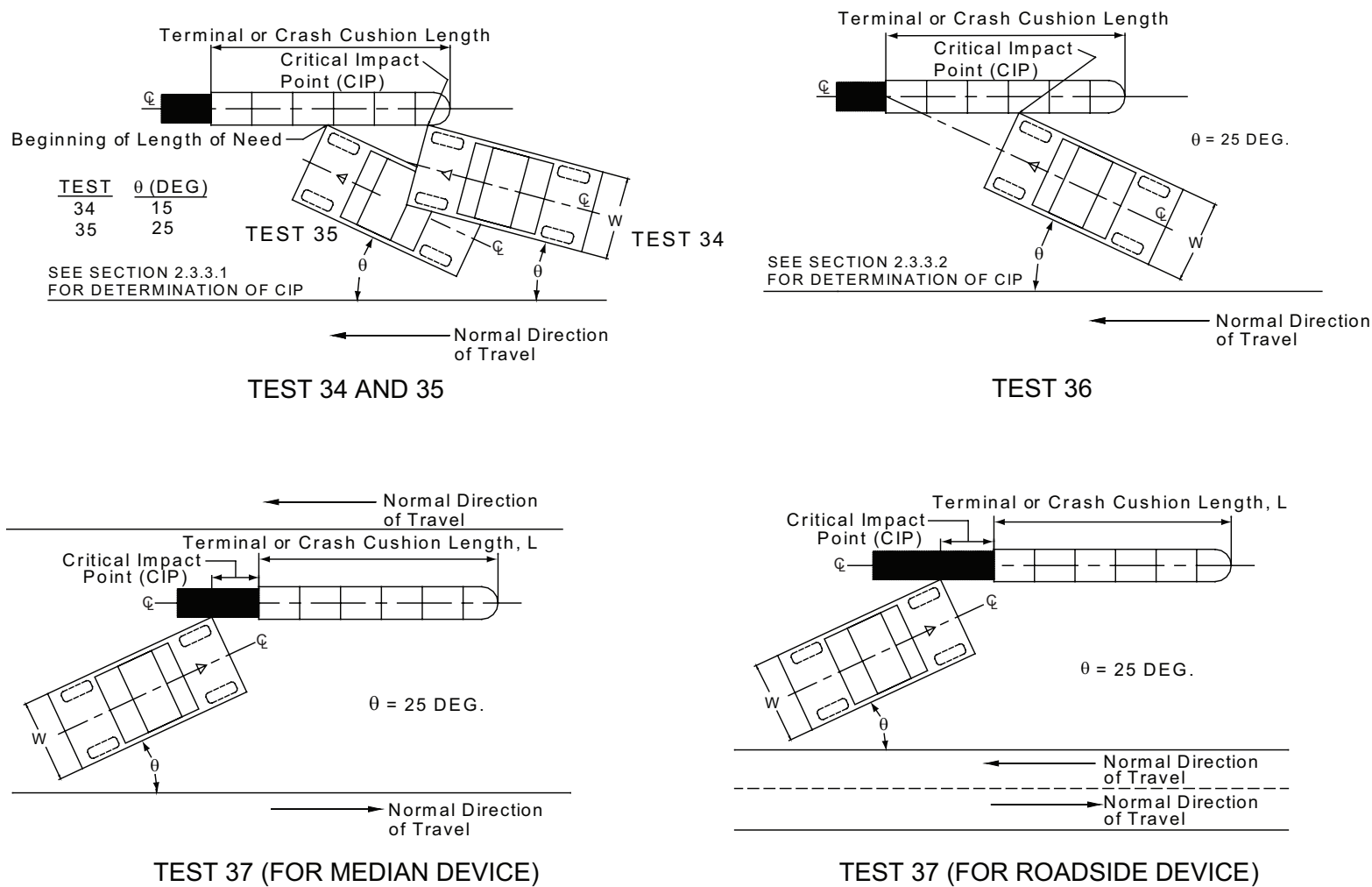
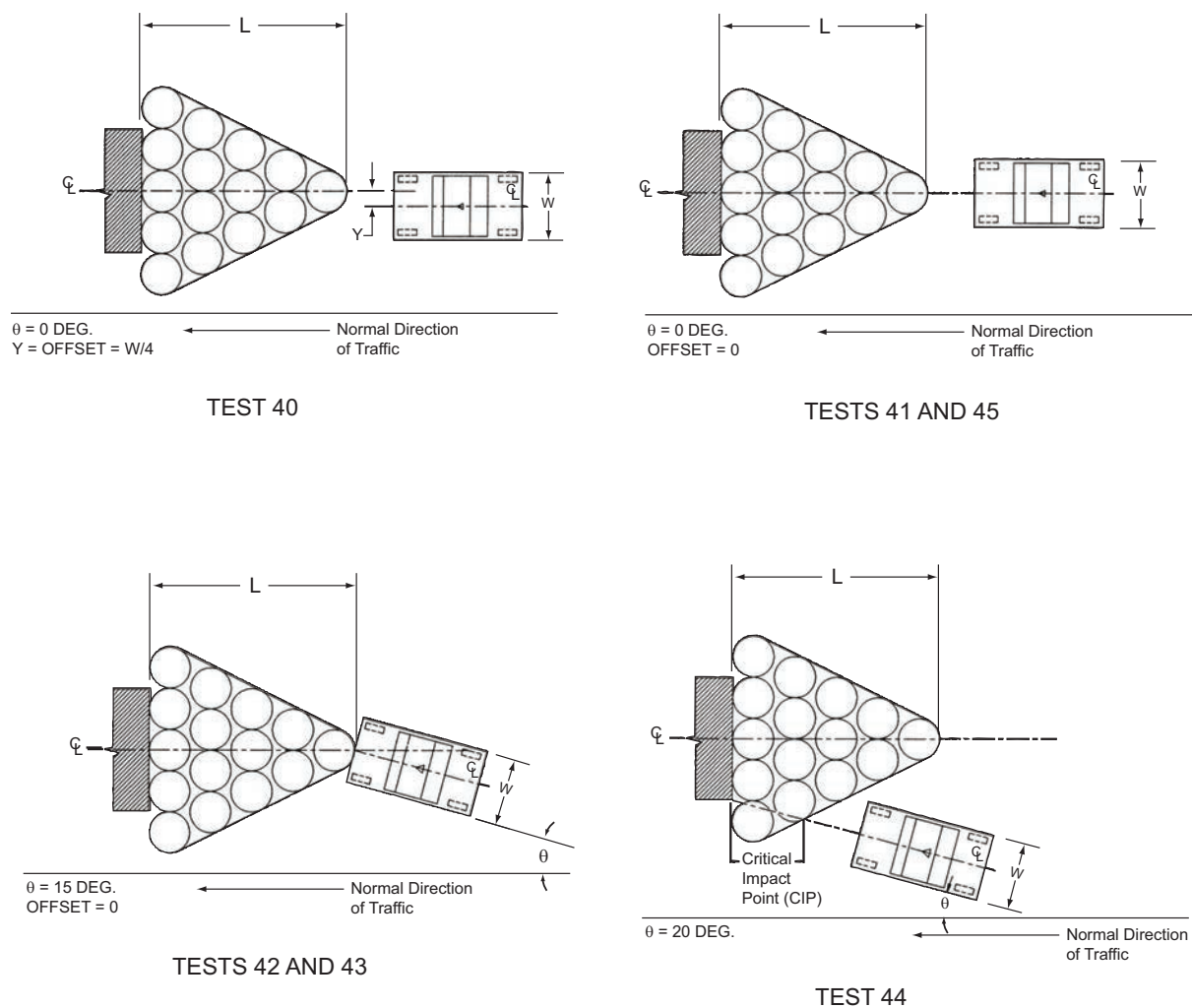


Figure 2-3A. Impact Conditions for Terminal and Redirective Crash Cushion Tests



NOTE: Recommended Tolerance on Impact Point in All Side Impacts = ± 300 mm

Figure 2-3A. Impact Conditions for Terminal and Redirective Crash Cushion Tests (continued)



NOTE: Recommended Offset Tolerance for All Tests = $\pm 0.05(W)$

Figure 2-3B. Impact Conditions for Non-Redirective Crash Cushion Tests

2.2.2.2 Description of Tests

TESTS 30 and 40

Tests 30 and 40 are designed to examine the risk of vehicle instability, particularly for narrow terminal and crash cushion systems. Although Tests 32 and 42 often exhibit higher occupant risk criteria, the risk of vehicle instability is higher for Tests 30 and 40. Hence, Tests 30 and 40 should be conducted even if a system successfully passes Tests 32 or 42.

These tests are conducted with the vehicle traveling parallel to the roadway and the center of the vehicle offset one quarter of its width to the left or right from the center of the safety feature. For purposes of locating the impact point for these tests, the center of a safety feature, such as a guardrail terminal, should be defined as the center of resistance for head-on impacts rather than the geometric center of the system. These tests are designed to primarily evaluate occupant risk and vehicle trajectory criteria. The vehicle offset should be chosen to maximize the risk of exceeding occupant risk or inducing vehicle instability. Consideration should be given to the direction of vehicle rotation induced by the vehicle offset as well as the potential for tire interaction with rails or other anchor components that do not move when the system is struck. For a W-beam guardrail terminal, the critical vehicle offset is typically toward the traffic side since vehicle contact with the backside support posts will maximize yaw rotation and the risk of instability. Vehicle offset to the field side might be considered when evaluating vehicle stability on sloped terrain behind the guardrail terminal. Dummy location, left or right, should also be selected to maximize vehicle yaw movement. The risk of vehicle instability can sometimes be increased by reducing the offset somewhat to allow the vehicle's tires to contact anchor components under the guardrail terminal or crash cushion.

TESTS 31 and 41

For devices intended to decelerate vehicles to a stop, these tests are designed to evaluate the capacity of the feature to absorb sufficient energy to stop the 2270P vehicle in a safe and controlled manner. For gating systems, these tests are intended to evaluate occupant risk and vehicle trajectory criteria during high-energy, head-on impacts. These tests are conducted with the vehicle approaching parallel to the roadway with the center of the vehicle aligned with the centerline of the terminal or cushion. Again, the centerline of the device is defined as the center of resistance during end-on impacts.

TESTS 32, 33, 42, and 43

These tests are intended to examine the behavior of terminals and crash cushions during oblique impacts on the end or nose of the system. For most features, occupant risk and vehicle trajectory are the primary concerns. Note that the impact angle for these tests should be selected from the range shown in Table 2-3 such that the risk of failure is maximized. Non-gating, redirective systems are designed to capture vehicles impacting the end of the device at an angle. In this case, the critical impact angle is believed to be one that maximizes the lateral load on the device, maximizes the risk that a vehicle will gate through the system, and maximizes occupant risk measures. Hence, it is recommended that non-gating, redirective systems be tested at 15 degrees. However, gating redirective systems are designed to allow a vehicle to penetrate behind the system, and increasing the lateral load on the device will likely accentuate the gating process. Therefore, gating redirective terminals and crash cushions should be tested at much lower impact angles, closer to the 5-degree minimum value. The appropriate

impact angle to be used in tests of non-redirective crash cushions is less clear. The crash cushion should be analyzed and impact angles selected to maximize occupant impact velocities and ridedown accelerations.

TEST 34

Test 34 is intended to evaluate the impact performance of terminals and crash cushions at the critical impact point (CIP) where the behavior of these devices changes from gating or capturing to redirection. Vehicle trajectory and occupant risk are the primary concerns for this test. Criteria for selecting the CIP for post-and-beam terminal or crash cushion systems are presented in Section 2.3.3.1.

Whenever practical, finite element analysis should be conducted to identify critical impact points for post-and-beam systems as well as other terminals and redirective crash cushions.

TEST 35

Test 35 examines the capacity of a terminal or crash cushion for containing and redirecting heavy passenger vehicles. For this test, a 2270P vehicle is directed into the system at the beginning of the length-of-need at an impact angle of 25 degrees. Note that, for non-gating crash cushions, the beginning of the length-of-need should be very near the nose of the crash cushion. In this case, Test 35 should involve a vehicle impacting on the very end of the system where cushion behavior changes from capturing to redirective. Hence, for non-gating systems, this test is essentially a CIP impact with a light truck test vehicle.

TEST 36

This test is designed to examine the behavior of terminals and redirective crash cushions when attached to rigid barriers or other very stiff features. For this test, the 2270P test vehicle is directed into the terminal or crash cushion at its CIP with respect to the transition to the backup structure. Note that some terminals, including most W-beam guardrail terminals, are not attached directly to a stiff barrier or backup structure. Test 36 is only recommended for terminals or cushions directly attached to very stiff barriers or backup structures. General guidelines for determining CIP locations for this test are included in Section 2.3.3.2. Whenever possible, finite element analyses should be used to determine the CIP for Test 36.

TEST 37

Test 37 examines the behavior of crash cushions and terminals during reverse-direction impacts. This test is recommended for any safety feature that will be placed within the clear zone of opposing traffic. This test involves a 2270P or 1100C vehicle striking the critical impact point (CIP) for reverse-direction impacts. CIP locations for reverse direction impacts vary greatly from one system to another and a generalized system for identifying these locations has yet to be developed. Note that the configurations shown in Figure 2-3A for Test 37 are intended for illustration purposes only and do not necessarily reflect the actual test configuration.

For most crash cushions with fender panels lapped against opposing traffic, the CIP should be selected to maximize the risk of snagging on the end of the last fender panel lapped in this manner.

Many crash cushions attached to concrete barriers incorporate a tapered section between the wider cushion and the narrower barrier face. In this situation, Test 37 should normally be configured to first strike the barrier or the tapered section in order to maximize the potential for snagging. The 2270P will generally be the critical vehicle for this test when a crash cushion is being evaluated.

For post-and-beam terminals utilizing a breakaway cable system, the 1100C will generally be the critical vehicle for this test, and the impact point should be selected to maximize the risk of the vehicle snagging on the anchor cable.

TESTS 38 and 45

Tests 38 and 45 are intended to examine the performance of crash cushions and end terminals during impacts by mid-size vehicles. The concern is that attenuator staging can be tuned to meet the testing requirements for the small car and heavy pickup truck without adequately accommodating mid-sized vehicles. For these tests, the centerline of the test vehicle is aligned with the centerline of the test article. Note that Tests 31 and 41 involve heavier vehicles impacting the systems under the same impact conditions. Thus, accelerometer data from Tests 31 and 41 can be used to identify if Tests 38 and 45 are needed. As described in Appendix G, accelerometer data from Tests 31 and 41 can be integrated to obtain the force versus deflection characteristics of the terminal or crash cushion. The force vs. deflection data can then be used to estimate the occupant impact velocity and ride-down acceleration for a 3,300-lb (1,500-kg) vehicle. Note that this analysis will be conservative because impact forces experienced during Tests 31 and 41 with the 2270P vehicle will be higher than those generated by a mid-sized vehicle due to the heavier mass and higher crush stiffness of the 2270P vehicle. If the force versus deflection analysis predicts that the terminal or crash cushion will meet evaluation guidelines for occupant impact velocity (OIV) and RA for a 3,300-lb (1,500-kg) vehicle, Test 38 or 45 is not recommended.

TEST 44

Test 44 is designed to evaluate the ability of a non-redirective crash cushion to safely stop a large passenger vehicle in **an impact along the side of the device**. For this test, the 2270P test vehicle is directed into the crash cushion at its CIP with respect to the transition to the backup structure. Note that non-redirective crash cushions are not designed to safely attenuate this impact and therefore occupant risk parameters, evaluation criteria H and I, are not among the recommended evaluation criteria. However, these values should be reported as a means for user agencies to estimate the potential risk of using non-redirective crash cushions. Impacting vehicles should remain stable and upright during this test. If a system truly has no redirective capacity, such as a sand inertial cushion, the centerline of the test vehicle should be directed at the corner of the shielded hazard as shown in Figure 2-3B. However, if a non-redirective crash cushion can be expected to provide some redirective capacity, general guidelines for determining CIP locations presented in Section 2.3.3.2 for Test 36 should be followed.

2.2.2.3 Other Terminals and Crash Cushion Systems

Some wide-area terminals or crash cushions may not be specifically addressed by the crash test matrix presented above. For example, bull-nose and short-radius guardrails function as terminals and crash cushions, but their asymmetric and/or large nose configurations can make identification of the appropriate impact points for some tests very difficult. For these systems, the designer and testing agency should attempt to design test matrices that explore critical elements of the safety feature while applying

the basic intent and framework of the recommended tests and evaluation criteria. Recommended test vehicles, impact speeds, and impact angles should be applied with the most critical impact points for the safety feature under consideration.

2.2.3 TRUCK- AND TRAILER-MOUNTED ATTENUATORS AND PORTABLE WORK-ZONE TRAFFIC CONTROL TRAILERS

2.2.3.1 General

Truck- and trailer-mounted attenuators (TMAs) are designed to protect motorists from impacts with stationary or slow-moving trucks utilized in work zones and maintenance operations. During a TMA crash, the support truck is accelerated forward as the impacting vehicle is decelerated. Hence, the total velocity change during a TMA impact is strongly related to the mass of the support truck. Heavier support trucks will produce higher impacting vehicle velocity changes and require greater energy dissipation by the TMA. On the other hand, support trucks that are too light could produce high accelerations for the operator and excessive roll-ahead distance, which is the length of travel of the support truck during the impact. The roll-ahead distance is used to identify the minimum required spacing between the support truck and construction or maintenance activities. Support truck operator risks and factors affecting roll-ahead distance are discussed in Section A2.2.3 of Appendix A. Therefore, truck- and trailer-mounted attenuators should be rated in terms of both the lightest and heaviest allowable support vehicle. Note that Tests 50, 51, and 52 described in the following sections should be conducted with the heaviest allowable support vehicle or a rigidly blocked support truck for unlimited support-truck weight while Test 53 should be conducted with the lightest allowable support vehicle.

During the tests, the support truck should be placed in second gear and the parking brake set. Note that the support truck's parking brake should be in good condition at the time of the test. TMAs designed for an unlimited support vehicle mass should be tested with the support truck blocked to prevent forward or lateral motion. Table 2-4 presents recommended crash tests and Figure 2-4 displays impact conditions for truck- and trailer-mounted attenuators (TMAs). Reference is made to Section 3.4.2.4 for support-truck parameters.

Portable work-zone traffic control trailers are common roadside fixed objects that are used in both temporary and permanent applications. These devices are often placed near the traveled way for maximum visibility. Left unprotected, these devices can pose a significant hazard, especially to the occupants of small cars. Therefore, it may be necessary in some instances to shield these trailers or to otherwise make them crashworthy. Shielding may be accomplished by placing the trailer behind a barrier or crash cushion. Safety treatments designed to be integral or attached to work-zone traffic control trailers should be subjected to Tests 50 and 51 from the truck- and trailer-mounted attenuator category.