

National Cooperative Highway Research Program

NCHRP Report 350

Recommended Procedures for the
Safety Performance Evaluation
of Highway Features

Transportation Research Board
National Research Council

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National Cooperative Highway Research Program

Report 350

Recommended Procedures for the Safety Performance Evaluation of Highway Features

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation officials, or the Federal Highway Administration, U.S. Department of Transportation.

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FOREWORD

By Staff
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This report is recommended to highway design engineers, bridge engineers, safety engineers, maintenance engineers, researchers, hardware developers, and others concerned with safety features used in the highway environment. It contains recommended procedures for evaluating the safety performance of various highway safety features. These procedures are based on a comprehensive literature review, an analysis of the state of the art for performance evaluation (including procedures adopted by foreign agencies), and the advice of a selected group of acknowledged experts. It is believed that this report will contribute toward providing safer highways.

Effective traffic barrier systems, end treatments, crash cushions, breakaway devices, truck-mounted attenuators, and other hardware must be used to achieve the highest levels of highway safety. Many devices have been developed by state agencies, universities, and private firms to address particular roadside safety concerns. 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 impact testing has been and will continue to be the most common method of evaluating the safety performance of guardrails, median barriers, bridge railings, crash cushions, breakaway supports, truck-mounted attenuators, work zone traffic control devices, and other hardware. Because a number of agencies in the United States conduct such tests, there is a need for uniformity in the procedures and criteria used to evaluate traffic barriers and other roadside safety features. There are also important precedents for promoting international harmonization of procedures to take advantage of relevant experience and research findings in other countries.

Procedures for full-scale vehicle crash testing of guardrails were first published in *Highway Research Correlation Services Circular 482* in 1962. This one-page document specified vehicle mass, impact speed, and approach angle for the crash tests. Although *Circular 482* did bring a measure of uniformity to traffic barrier research then being performed at several research agencies, a number of questions arose that were not addressed.

NCHRP Project 22-2 was initiated at Southwest Research Institute in 1973 to address the questions that were not covered in *Circular 482*. The final report was published as "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," *NCHRP Report 153*. This 16-page document was based on technical input from more than 70 individuals and agencies as well as extensive deliberations by a special ad hoc panel. Several parts of the document were known to be based on inadequate information, but coverage of these areas was included to provide a more complete set of testing procedures. These procedures gained wide acceptance following their publication in 1974, but it was

recognized at that time that periodic updating would be needed; and, in January 1976, TRB Committee A2A04 accepted the responsibility for reviewing the efficacy of the procedures. Questionnaires were submitted to committee members to identify areas of the document that needed revision. The responses generally fell into two categories: (1) minor changes requiring modified treatment of particular problem areas; and (2) major changes that would require broadening the scope to include, for example, testing with trucks and buses, reevaluating the criteria for impact severity, and treating special highway appurtenances such as construction barriers. The committee addressed the minor changes through special committee action; and *Transportation Research Circular 191*, published in 1978, was the product of this effort.

NCHRP Project 22-2(4) was initiated in 1979 by Southwest Research Institute to address the major changes. Its objective was to review, revise, and expand the scope of *Circular 191* to reflect current technology. The final report of **NCHRP** Project 22-2(4) was published as *NCHRP Report 230*, "Recommended Procedures for the Safety Performance Evaluation of Highway Safety Appurtenances," in 1980. 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.

In 1987, American Association of State Highway and Transportation Officials (AASHTO) recognized that the evolution of roadside safety concepts, technology, and practices necessitated an update to *Report 230*. The reasons included significant changes in the vehicle fleet, the emergence of many new barrier designs, increased interest in matching safety performance to levels of roadway utilization, new policies requiring the use of safety belts, and advances in computer simulation and other evaluation methods. **NCHRP** Project 22-7 was approved to consider these factors and to prepare the update to *Report 230*.

The research team of Principal Investigator Dr. Hayes Ross, Jr., Texas A & M University, and Co-Principal Investigator Mr. Jarvis Michie, Dynatech Engineering, began this effort in 1989 with a series of white papers on the subjects of the test matrix, assessment procedures and criteria, specification and control of test parameters, in-service evaluation, use of surrogate test vehicles, computer simulations and other evaluation procedures, instrumentation of crash testing, the purpose of the document, and conversion to SI units. (Unedited drafts of these documents can be obtained on request from the **NCHRP**.) The panel reviewed each white paper and provided comments on the issues raised in them. A meeting of the panel was held to discuss the various issues, debate the implications for an updated set of procedures, and develop a consensus on the procedures that would be incorporated in the update. The research team prepared the first draft of the updated procedures after this meeting. This draft was thoroughly reviewed by the panel and a second meeting was held to discuss the report and establish panel consensus on the updated procedures.

The second draft of this document was mailed to some 100 individuals, and comments were received from about 65. The project panel met a third time to consider the review comments and determine where changes were needed in the updated procedures. Although the report originated with the research agency, each recommendation has the consensus endorsement of the **NCHRP** Project Panel. Where recommendations are founded on less than clear-cut evidence, the judgment of the project panel prevailed.

NCHRP Report 350 represents a comprehensive update of the procedures for safety performance evaluation. *Report 350* differs from *Report 230* in the following ways:

1. It is presented as an all-metric document in anticipation of the U.S. conversion to SI units of measurement. Hard conversions were made in the update process, which will

alter the mass, speeds, and tolerances used in testing. For example, tests previously specified for 60 mph (97 km/h) are now specified at 100 km/h. The impacts of such increases of speed on the kinetic energy of the tests were recognized and appropriate criteria adjustments made.

2. It provides a wider range of test procedures to permit safety performance evaluations for a wider range of barriers, terminals, crash cushions, breakaway support structures and utility poles, truck-mounted attenuators, and work zone traffic control devices.

3. It uses a $\frac{3}{4}$ -ton pickup truck as the standard test vehicle in place of the 4500-lb passenger car to reflect the fact that almost one-quarter of the passenger vehicles on U.S. roads are in the "light truck" category. This change was made recognizing the differences in wheel bases, bumper heights, body stiffness and structure, front overhang, and other vehicular design factors.

4. It defines other supplemental test vehicles including a mini-compact passenger car (700 kg), single-unit cargo trucks (8000 kg), and tractor-trailer vehicles (36,000 kg) to provide the basis for optional testing to meet higher performance levels.

5. It includes a broader range of tests for each category of safety feature to provide a uniform basis for establishing warrants for the application of roadside safety hardware that consider the levels of use of the roadway facility. Six basic test levels are defined for the various classes of roadside safety features, and a number of optional test levels are defined to provide the basis for safety evaluations to support more or less stringent performance criteria.

6. The report includes guidelines for the selection of the critical impact point for crash tests on redirecting-type safety hardware.

7. It provides information related to enhanced measurement techniques related to occupant risk and it incorporates guidelines for device installation and test instrumentation.

8. The three basic evaluation criteria categories remain the same. The occupant risk criteria retains the use of the flail space model, but defines preferred and maximum levels of occupant impact velocity and acceleration. The lateral occupant impact velocity limits were altered to be equivalent to longitudinal limits to reflect recent research findings. The redirection criteria were altered to incorporate a limiting 12 m/s vehicular velocity change requirement in the longitudinal direction.

9. It reflects a critical review of methods and technologies for safety-performance evaluation, such as surrogate test vehicles and computer simulations, and incorporates state-of-the-art methods in the procedures.

10. It provides optional criteria, established by others, for side impact testing.

The evolution of the knowledge of roadside safety and performance evaluations is reflected in this document. Inevitably, parts of this document will need to be revised in the future, but it is the consensus opinion of the project panel and the many reviewers of these procedures that this document will effectively meet the needs for uniform safety performance evaluation procedures into the 21st century.

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RECOMMENDED PROCEDURES FOR THE SAFETY PERFORMANCE EVALUATION OF HIGHWAY FEATURES

SUMMARY

Procedures are presented for conducting vehicle crash tests and in-service evaluation of roadside safety features or appurtenances. The features covered by these procedures include (1) longitudinal barriers such as bridge rails, guardrails, median barriers, transitions, and terminals; (2) crash cushions; (3) breakaway or yielding supports for signs and luminaries; (4) breakaway utility poles; (5) truck-mounted attenuators; and (6) work zone traffic control devices. The purpose of the procedures is to promote the uniform testing and inservice evaluation of roadside safety features so that highway engineers may confidently compare the safety performance of designs that are tested and evaluated by different agencies. These procedures are presented in the form of guidelines that describe how a feature should be tested and evaluated. The identification of specific new, existing, or modified features for testing and evaluation; the selection of a level of service that the feature is to meet; and the establishment of acceptable performance criteria for an agency are policy decisions that are beyond the purview of this document. The procedures are directed at the safety performance of roadside safety features; other service requirements such as economics and aesthetics are not considered here.

These procedures are devised to subject roadside safety features to severe vehicle impact conditions rather than to typical or average highway situations. Although the innumerable highway-site and safety-feature application conditions that exist are recognized, it is impractical or impossible to duplicate these in a limited number of standardized tests. Hence, the approach has been to normalize test conditions: straight longitudinal barriers are tested although curved installations exist; flat grade is recommended even though installations are sometimes situated on sloped shoulders and behind curbs; idealized soils are specified although roadside safety hardware are often founded in poor soil or frozen ground. These normalized test conditions have a significant effect on a feature's performance but are of secondary importance when comparing results of two or more systems.

For vehicle crash testing, specific impact conditions are presented for vehicle mass, speed, approach angle, and point on the safety feature to be hit. Standard test vehicle types are defined for mini-compact and subcompact passenger cars, standard $\frac{3}{4}$ -ton pickup trucks, single-unit trucks, and tractor-trailer cargo trucks. Impact speeds range from 35 to 100 km/h (approximately 20 to 60 mph), and approach angles vary from 0 to 25 degrees. Three primary appraisal factors are presented for evaluating the crash test performance:

structural adequacy, occupant risk, and after-collision vehicle trajectory. Depending on the safety feature's function, it should contain, redirect, permit controlled penetration of the impacting vehicle, or permit a controlled stop in a predictable manner to satisfy structural adequacy requirements. Occupant risk relates to the degree of hazard to which occupants in the impacting vehicle would be subjected. It is measured in terms of the velocity at which a hypothetical unrestrained occupant strikes some part of the vehicle interior such as the instrument panel, window, or door, and the subsequent occupant ridedown accelerations. The after-collision vehicle trajectory is assessed based on the probable involvement of other traffic due to the path or final position of the impacting car and on the chances of undesirable post-impact vehicle behaviors such as pocketing or snagging. It is recognized that vehicle crash tests are complex experiments and are difficult to replicate because of the imprecise control of test conditions and the sometimes random and unstable behavior of dynamic crush and fracture mechanisms. Accordingly, care should be exercised in interpreting the results.

In-service evaluation is used in the final stage of development of new or extensively modified roadside safety features and has the purpose of appraising actual performance during a broad range of collision, environmental, operational, and maintenance situations for typical site and traffic conditions. This report updates the guidelines for in-service evaluation first provided in *NCHRP Report 230*, recognizing the complex nature of vehicular accidents and the limited resources of agencies responsible for monitoring the performance of new or modified safety features.

Appendices to this report provide (a) a commentary on the basis for the procedures; (b) soil specifications for the installation of safety features; (c) specifications for the instrumentation of the tests; (d) a summary on the analytical and experimental tools that can be used in the research and development phase for safety features; (e) a methodology for quantifying the damage to the occupant compartment of a test vehicle; (f) a description of calculation procedures for alternate measures of occupant risk (e.g., THIV, PHD, and ASI); and (g) a methodology for conducting and evaluating side impact tests.

CHAPTER 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 30 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.

Although these guidelines are representative and applicable to an array of highway features and traffic conditions, they should not be viewed as 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.

With the guidelines, a given feature may be tested to one of six "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). A feature designed and tested for a low test level would generally be used on a low service level roadway; for example, a rural collector or local road, an urban street, or perhaps in a restricted work zone. A feature designed and tested for a high test level would typically be used on a high service level roadway; for example, a freeway.

It must also be noted that features that meet a given test level will generally have different performance characteristics. A concrete barrier and a cable barrier can be designed to satisfy a given test level, but it is obvious that the cable barrier will deflect much more, impact forces will be less for the cable barrier, and vehicle trajectory will certainly not be the same for both barriers. A terminal can be designed to have full redirection capabilities along its entire length (termed a *nongating terminal*), or it can be designed to allow controlled penetration along a portion of its length (termed a *gating terminal*). Both designs can be made to satisfy a given test level. 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 *nonredirective crash cushion*). 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 have application. That determination rests with the appropriate transportation agency responsible for the implementation of the safety feature.

These guidelines supersede those contained in *NCHRP Report 230 (1)*. Major revisions incorporated herein relative to *Report 230* include (a) changes to the test vehicles, (b) changes to the number and impact conditions of the test matrices, (c) adoption of the concept of "test levels" as opposed to "service levels," (d) changes to the evaluation criteria, (e) inclusion of test guidelines for additional features, and (e) adoption of the International System of Units (SI). The **SI** was adopted in concert with national efforts to convert the English system of units to the internationally accepted SI.

Procedures presented herein involve vehicular tests to evaluate the impact performance of permanent and temporary highway safety features. Performance is evaluated in terms of the degree of hazard to which occupants of the impacting vehicle would be exposed, the structural adequacy of the safety feature, the hazard 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.

1.2 DEVELOPMENT OF A SAFETY FEATURE

Development of a safety feature from its inception to the time it becomes operational is often a long and arduous process. Depending on its developmental phase, a feature is generally placed in one of three categories: (1) research and development, (2) experimental, and (3) operational. During the research and development phase, the design evolves and is eventually subjected to a set of crash tests. Results of the crash tests are assessed in accordance with a set of evaluation criteria. If the feature satisfies the evaluation criteria, it is then placed in the experimental phase. Subject to interest by user agencies, it may then be installed, often on a limited basis. The purpose of the experimental phase is to closely monitor the in-service performance of the

feature. If it performs satisfactorily in service, it may then be placed in the operational phase; but its performance should continue to be monitored.

Shown in Figure 1.1 is a flow chart illustrating the process through which a new safety feature is typically subjected. Steps 1 through 4 involve the research and development phase. Factors that should be considered and design techniques that may be used during this phase are indicated. Note that during step 3 it may be beneficial to use analytical and experimental tools described in Appendix D. Step 4 is addressed in Chapters 2 through 6. If a device meets the recommended impact performance criteria, it is then classified as experimental and steps 6 through 9 may then be performed. If acceptable to a user agency, standard plans are prepared (step 8) and the feature is installed on a limited basis. Step 9 involves in-service evaluation, and recommended procedures for conducting this evaluation are given in Chapter 7. This step is perhaps the most important part of the development of a feature. If its in-service is acceptable, it may then be classified as operational (step 11) and fully implemented. However, monitoring of the in-service performance of the device should continue in this phase (step 12).

To be noted is that, while there are specific guidelines (as presented herein) for determining if a device is acceptable as an experimental device, there are no widely accepted, specific criteria to assess its in-service performance. Consequently, considerable judgment must be exercised in determining when a device has met the in-service requirements and thus becomes operational. Some agencies may choose to skip steps 9 and 10, declaring the feature operational on the basis of expert opinion. However, it is strongly recommended that step 12 never be omitted.

1.3 PERFORMANCE GOALS

A goal of a highway safety feature is to provide a forgiving roadway and roadside for an errant motorist. The safety goal is met when the feature either contains and redirects the vehicle away from a hazardous area, decelerates the vehicle to a stop over a relatively short distance, 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 pavement. 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 run-off-the-road incident.

As discussed in Section 1.2, the safety performance of a highway feature cannot be measured by a series of crash tests only. Testing must be viewed as a necessary but not sufficient condition to qualify a feature for operational status. Tests results are judged on the basis of evaluation criteria presented in Chapter 5.

1.4 PERFORMANCE LIMITATIONS

Even the most carefully researched device has performance limits dictated by physical laws, crashworthiness of vehicles, and

limitation of resources. 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 timber utility poles may be so massive that the impacting vehicle is abruptly decelerated, thus limiting achievable safety 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. 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. Note that no provisions are made herein for the design and testing of safety features for two-wheeled vehicles-powered or unpowered. Longitudinal barriers that will contain and redirect the smaller passenger cars and yet have strength capability to redirect a tractor-trailer or intercity bus are relatively expensive. Seemingly insignificant site conditions such as curbs, slopes, and soft soil conditions can cause or contribute to the unsuccessful performance of a safety feature.

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.

While it is to be expected that certain features, meeting all test and evaluation criteria recommended herein, will have untested "windows of vulnerability" in service, the corollary of this is also to be expected. That is, it is to be expected that certain features not meeting all test and evaluation criteria recommended herein will still be cost-effective alternatives for selected in-service applications.

1.5 ORGANIZATION OF REPORT

Chapter 2 describes the test parameters, including those associated with the test facility, the test article, and the test and its simulated occupants. Chapter 3 gives the test conditions recommended for each of the respective features. It also presents recommended tolerances on impact conditions and a procedure for identifying the critical impact point for certain features. Chapter 4 describes the data acquisition systems recommended and identifies parameters that should be measured before, during, and after the test. The evaluation criteria used to assess test results are contained in Chapter 5. Chapter 6 recommends the manner in which a given test and its results are to be documented. Chapter 7 contains guidelines on how the in-service performance of a feature should be evaluated. Appendix A is a commentary on those items contained in Chapters 2 through 6 and presents further elaboration and discussion. Appendix B contains soil specifications, reproduced with permission from the American Association of Highway and Transportation Officials, and Appendix C contains instrumentation specifications, reproduced with permission from the Society of Automotive Engineers, Inc. Appendix D summarizes analytical and experimental tools that can be used in the research and development phase; Appendix E contains a methodology for quantifying the damage to the occupant compartment; Appendix F describes calculation procedures for the Theoretical Head Impact Velocity (THIV), Post-Impact

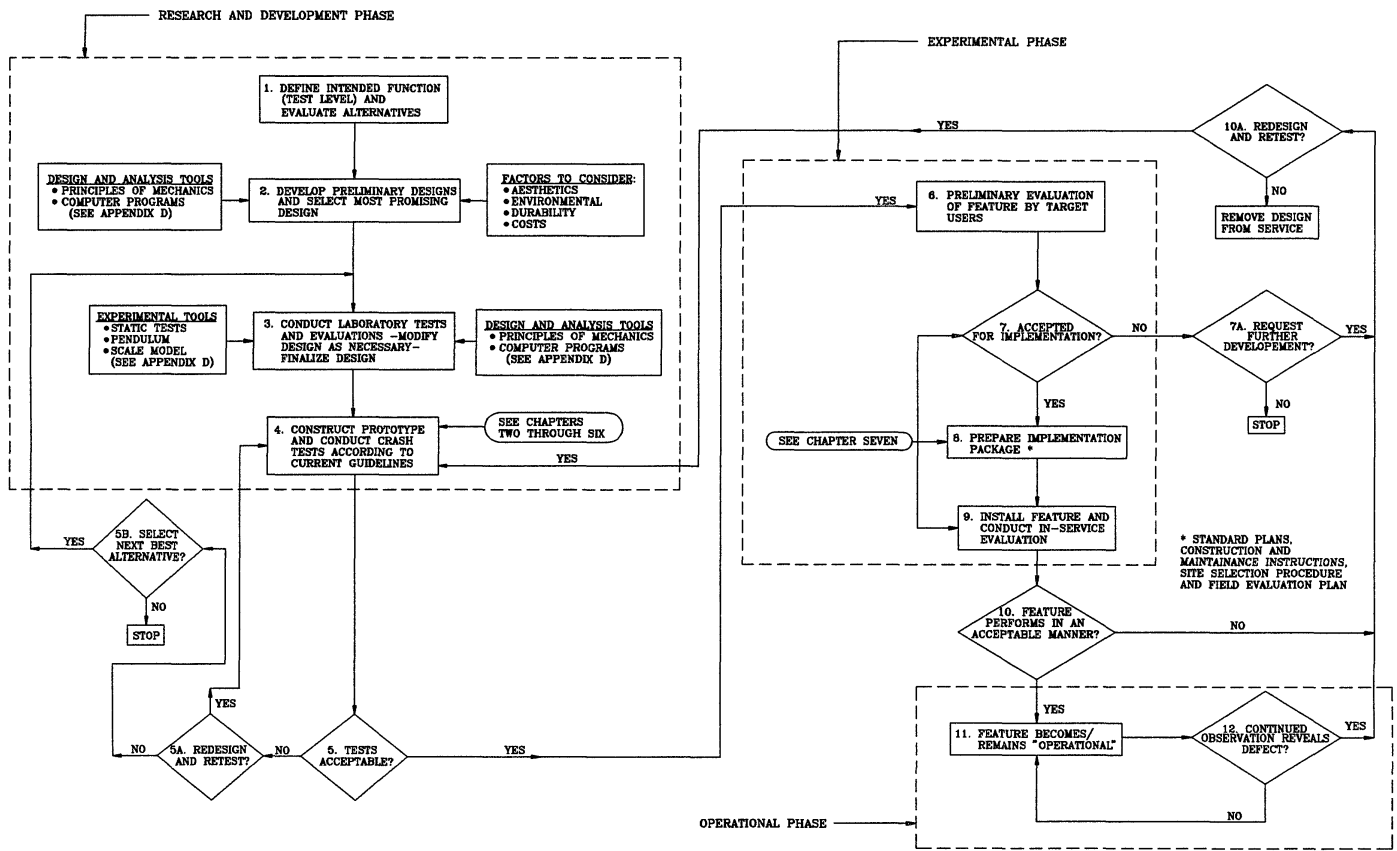


Figure 1.1. Flow chart for development of a safety feature.

Head Deceleration (PHD), and the Acceleration Severity Index (ASI); and Appendix G contains a methodology for conducting and evaluating side impacts. Appendix H contains the references and bibliography, and Appendix I is a glossary of terms. Sample SI conversion factors are presented in Appendix J.

1.6 INTERNATIONAL HARMONIZATION OF PERFORMANCE STANDARDS

Concurrent with the preparation of this report, the European Committee for Standardization (CEN) was preparing a similar

document (77). Discussions were held to explore ways impact performance standards between the U.S. and CEN could possibly be harmonized. However, scheduling deadlines precluded the development of substantive agreements. Nonetheless, based on expressed interests by U.S. government agencies and CEN agencies, it is expected that common standards will be adopted in future reports, at least for certain elements of the test and evaluation process. Toward this end, it was decided to incorporate the SI system of units herein. Furthermore, it is suggested that certain evaluation criteria adopted by CEN be calculated and reported for tests in the U.S. for purposes of comparison with comparable U.S. criteria (see Section 5.3).

CHAPTER 2

TEST PARAMETERS

2.1 GENERAL

Highway safety features are evaluated for a particular test level through a series of vehicular crash tests for a limited range of impact conditions, as presented in Chapter 3. Many important test parameters have been standardized to arrive at practical stratification of tests (test matrices) and to enhance the degree of test replication. Care must be exercised in the interpretation of test results and in the projection of the results to in-service performance. Good performance under ideal test conditions does not ensure comparable performance under in-service conditions. As discussed in Chapter 1, the evaluation process should not stop with successful completion of tests recommended herein. In-service evaluation of the feature is perhaps more important than crash test evaluation and should be pursued as recommended in Chapter 7.

2.2 TESTING FACILITY

A flat surface, preferably paved, should be used when accelerating the test vehicle to the desired speed and to provide for unrestricted trajectory of the vehicle following impact. The surface should be free of curbs, swales, ditches, or other irregularities that could influence impact or post-impact behavior of the vehicle except when test conditions require such features. If necessary, a flat compacted soil or sod surface should adjoin the paved approach area to replicate conditions for safety features normally surrounded by an unpaved surface, so that post-impact vehicular behavior can be properly assessed.

2.2.1 Soil

Impact performance of some features depends on dynamic soil-structure interaction. Longitudinal barriers with soil embedded posts and soil-embedded support structures for signs and luminaires are such features. When feasible, these features should be tested with soil conditions that replicate typical inservice conditions. Unfortunately, soil conditions are known to vary with time and location, even within relatively small geographical areas. Therefore, except for special test conditions, it is necessary to standardize soil conditions for testing. In the absence of a specific soil, it is recommended that all features whose impact performance is sensitive to soil-structure interaction be tested with soil described in Section 2.2.1.1. Product developers and user agencies should assess the potential sensitivity of a feature to foundation conditions, and if the feature is

likely to be installed in a soil that could be expected to degrade its performance, testing in one or more of the special soils described in Section 2.2.1.2 may be appropriate.

For tests involving soils recommended in Sections 2.2.1.1 and 2.2.1.2, the length, width, and depth of the embedment material should be sufficient to effectively eliminate influence of native soil on impact performance. If these dimensions cannot be determined, it is recommended the test soil depth be approximately 1.2 times the embedment length of the test article and that the lateral extent of the test soil, outside an envelope of the embedded portion of the test article, be approximately 1.3 times the embedment length.

2.2.1.1 Standard Soil

It is recommended that the standard soil meet AASHTO standard specifications for "Materials for Aggregate and Soil Aggregate Subbase, Base and Surface Courses," designation M 14765 (1990), grading A or B (see Appendix B, Part 1). It should be compacted in accordance with AASHTO *Guide Specifications for Highway Construction*, Sections 304.05 and 304.07 (see Appendix B, Part 3). The soil should be recompacted, as necessary, before each test to meet density requirements of the *Guide Specifications*. The soil should be well drained at the time of the crash test. The test should not be performed if the ground is frozen or if the soil is saturated unless the test is specifically designed to evaluate these conditions (see next section).

2.2.1.2 Special Soils

The following guidelines may be used to evaluate a feature in a weak, saturated, or frozen soil.

Weak Soil. It is recommended the weak soil meet AASHTO standard specification for "Fine Aggregate for Portland Cement Concrete," AASHTO designation M 6-87 (see Appendix B, Part 2). The soil should be compacted in accordance with AASHTO *Guide Specifications for Highway Construction*, Sections 304.05 and 304.07 (see Appendix B, Part 3). The soil should be recompacted, as necessary, before each test to meet density requirements of the *Guide Specifications*. The soil should be well drained at the time of the crash test.

Saturated Soil. The "standard soil" and "weak soil" previously described may be used to evaluate impact performance of a feature under saturated soil conditions. Moisture content of the soil should replicate expected in-service conditions.

Frozen Soil. The "standard soil" and "weak soil" described may be used to evaluate impact performance of a feature under

frozen soil conditions. The degree to which the soil is frozen, measured in terms of depth and temperature, and its moisture content should replicate expected in-service conditions.

2.2.1.3. *Embedment of Test Article*

Within the range of expected in-service conditions, the depth and method of embedment should be those likely to reveal the poorest performance of the test article. This may not be predictable, in which case testing should be done under sufficient embedment conditions to reveal the worst performance. The method used in embedding the test article should replicate the method by which the feature will be embedded in service. A sign support is typically embedded by driving the post or stub directly into the soil, by inserting the support in a drilled hole and then backfilling the soil, or by placing the support or stub in a concrete footing. Similar methods are used for embedment of a longitudinal barrier post. Most luminaire support poles are supported by a concrete footing and most utility poles are placed in a drilled hole and then the soil is backfilled.

Some testers have developed universal foundations for testing breakaway devices consisting of multiple-use base plates supported on a very rigid concrete footing. While these foundations reduce testing costs, they effectively eliminate soil-foundation interaction. They also raise questions about feature-to-foundation interface friction and anchor bolt rigidity. If it cannot be shown that these effects are insignificant, the test report should, at a minimum, alert the user agency of potential problems and provide recommendations for foundation systems that will ensure proper breakaway performance.

2.2.2. **Special Structures**

Ends of roadside and median barriers must generally be anchored by terminal sections, bridge rails must be connected to a deck, and transitions are often attached to a rigid bridge end or wing wall on the downstream end of the transition. It is preferable that in-service designs of these auxiliary structures be used in the crash test when feasible. For example, when testing a roadside barrier, it is preferable that the ends be terminated as they would in service. When this is not feasible, special structures must be constructed. A key requirement of a special end anchorage device for a longitudinal barrier is that it have the capability to resist tensile loads developed in the rail.

Testing of a bridge rail will, in general, require a special support structure, i.e., a simulated bridge deck. For a nonrigid bridge rail where lateral deflection is of concern, the structure to which the railing is attached should simulate edge conditions so that the effect of vehicular penetration beyond the edge of the deck can be properly evaluated. Regardless of the rail's strength, it may be desirable to evaluate structural adequacy of the deck itself for the impact conditions, in which case the deck structure should have the same strength and properties as the in-service structure.

If a universal or generic deck is used in a bridge rail test, it is desirable that impact loads imposed on the deck be measured or computed from measured vehicular response and reported. By so doing, a user agency will have some guidance on how to design a deck that differs from the one used in the test. Procedures

that may be used to estimate impact loads from measured vehicular accelerations are presented in references 17 and 72. For tests of a flexible-to-a-rigid longitudinal barrier transition, a prototype bridge end structure or wing wall structure must be constructed. Length, strength, and geometry of the prototype should be sufficient to approximate impact response expected of the in-service bridge end or wing wall. Section 2.3.2.1 contains further recommendation on the prototype bridge end.

2.3. **TEST ARTICLE**

2.3.1. **General**

All key elements or materials in the test article that contribute to its structural integrity or impact behavior should be sampled, tested, and the results documented in the test report. Physical and chemical material properties can generally be obtained from the supplier providing the test article(s). To ensure that all critical elements are considered, a careful after-test examination of the test article is essential. Materials should be tested independently when a failure occurs.

Material specifications such as ASTM, AASHTO, and so forth, should be reported for all key elements. Results of random sample tests should confirm that stated specifications have been met and that key elements in the test article were representative of normal production quality. The tester should offer a judgment on effects marginal materials or materials that significantly exceed minimum specifications might have on performance of the test article. In addition, specified but unverified properties of all other materials used in the test article should be reported.

The test article should be constructed and erected in a manner representative of in-service installations and should conform to specifications and drawings of the manufacturer or designer. To assure uniformity and integrity of structural connections, current American Welding Society specifications for highway bridges, Aluminum Association Specifications for Aluminum Bridges and Other Highway Structures, American Institute of Steel Construction bolting procedures, and other relevant documents should be used as appropriate. Deviations from fabrication, specification, or erection details should be delineated in the test report.

2.3.2. **Installation Details**

2.3.2.1. *Longitudinal Barriers*

For tests examining performance of the length-of-need section, rails or barrier elements should be installed straight and level and anchored. Horizontally curved installations, sloped shoulders, embankments, dikes, and curbs should be avoided for general performance tests; when used, nonstandard features should be reported. As a general rule, length of the test section excluding terminals or end anchorage devices should be at least three times the length in which deformation is predicted but not less than 23 m for a rigid barrier (one for which little, if any, lateral displacement is anticipated) and 30 m for a flexible barrier such as a metal beam and post roadside barrier. Length of the test section should be such that (1) terminals or end anchorage devices do not influence in an abnormal manner the dynamic behavior of the barrier and (2) the ability of the barrier to contain and redirect

the test vehicle in the recommended manner can be clearly ascertained. Exceptions to recommended lengths can be made provided the installation satisfies these two requirements.

A free-standing, unanchored barrier, such as a precast, segmented concrete barrier whose impact performance depends in part on frictional resistance between it and the surface it is resting on, should be tested on a surface that replicates the type it will be placed on in service. If it will be placed on more than one surface in service, it should be tested on the one surface likely to have the most adverse effect on performance, usually the one having the least frictional resistance. Type of surface as well as end anchorages or terminals used should be reported.

The barrier system used for a transition test should be oriented as it would in service. As a general rule, transitions of most concern are those that serve to connect a less stiff barrier on the upstream side to a more stiff barrier on the downstream side, such as the transition from a flexible roadside or median barrier to a rigid bridge rail. In such cases, length, strength, and geometry of the prototype bridge rail or wing wall should be sufficient to approximate impact response expected of the in-service bridge rail or wing wall. It is recommended that the length of the prototype bridge rail or wing wall be 5 m at a minimum. A minimum of 15 m of the more flexible barrier is recommended, exclusive of a properly anchored end.

In some cases, the transition serves to connect longitudinal barriers with similar lateral stiffness but with different geometry. In such cases, a minimum of 15 m each of the adjoining barriers is recommended, exclusive of a properly anchored end.

2.3.2.2 Terminals and Crash Cushions

Reference should be made to Section 3.2.2 for recommendations relative to the manner in which a terminal or crash cushion should be oriented with respect to the vehicular approach direction. When testing terminals, the test article should be erected on level grade. As a rule, a 30-m length-of-need longitudinal barrier section should be attached to the terminal and anchored at the downstream end. If the terminal is designed for a specific longitudinal barrier, the length-of-need section used in the test should be composed of the specific barrier. Exceptions to the recommended length for the length-of-need section are permissible provided the ability of the terminal to stop, contain and redirect, or allow controlled penetration of the test vehicle in the recommended manner can be clearly ascertained.

A rigid, nonyielding backup structure should be used to simulate a highway feature (such as a bridge pier, elevated gore, or bridge end) when appropriate. For crash cushions having side hit redirection capability designed to be struck on one side by direct traffic and on the other side by opposing traffic, the test article should be installed with side hit deflector hardware oriented to accommodate both types of side hits. The crash cushion should be anchored as required by specifications or drawings.

2.3.2.3 Support Structures, Work Zone Traffic Control Devices, and Breakaway Utility Poles

Reference should be made to Section 3.2.3 for recommendations relative to the manner in which a support structure, a work zone traffic control device, or a breakaway utility pole should be

oriented with respect to the vehicular approach direction. Testing should verify breakaway or yielding features designed to function identically when impacted from specific directions, such as a breakaway base designed for front or rear impacts, or those features designed to function identically when impacted from any direction, e.g., a breakaway base designed for omnidirectional impacts. Support systems should be fully equipped with full height structures, including sign, mailbox or mailboxes, call box, and mast arm for luminaire. For tests of a luminaire support, it is preferable that an actual luminaire be used rather than a substitute equivalent weight that has often been used in the past. Tests have shown the luminaire/ballast can break loose during impact and consequently may present a hazard to other motorists or to occupants of the impacting vehicle. A full-length utility pole should also be used together with associated cross-arm(s), down guys, and conductors (lines).

The test may involve multiple supports such as multiple mailbox supports or multiple, closely spaced drums in a work zone. Orientation and spacing of these supports should be representative of in-service conditions.

Occasionally, a work zone traffic control device such as a barricade or a plastic drum will overturn or will intentionally be placed in an overturned position along the shoulder in a work zone. A barricade may typically be placed so that its panels are parallel rather than perpendicular to traffic. As such, these devices may pose a greater risk to an errant motorist than in their normal or upright position. If there is a reasonable expectation that such a device will likely be in this orientation during service, it should be tested in the overturned position, provided this orientation poses a greater risk to the motorist than in its normal position. If it cannot be determined which position is more critical, tests in both the normal and the overturned or rotated position should be conducted.

For tests of a sign support system, the area of the sign panel should approximate that of the largest panel that would normally be used on the support system. Sign panel material should be that normally used or to be used on the support system. If panels of different materials, such as plywood, sheet metals, or fiber reinforced plastics, are used with the support system, the test should be conducted with the material expected to pose the greater risk to occupants of the impacting vehicle. If it cannot be determined which material is most critical, it is recommended the test be conducted with the panel of greatest mass. Aspect ratio of the sign (height-to-width ratio) should be typical of the largest panel that would normally be used on the support system. Mounting height of the sign panel (distance from ground to bottom of panel) should be the minimum height the panel would normally be mounted in service unless it can be shown that a higher mounting height would pose a greater risk to occupants of the impacting vehicle.

For tests of a mailbox support system with a single mailbox, the mailbox should be the largest that would normally be used on the support system. For tests of a mailbox support system with multiple mailboxes, the number and size of mailboxes should be the largest that would normally be used on the support system.

2.3.2.4 Truck-Mounted Attenuators (TMA)

For tests with the 700C or 820C vehicles, the supporting truck should be placed against a rigid barrier to prevent any forward movement.

TABLE 2.1. Recommended properties of 700C, 820C, and 2000P test vehicles

Property	700C (Small Car)	820C (Small Car)	2000P (Pickup Truck)
MASS (kg)			
Test Inertial	700 ± 25	820 ± 25	2000 ± 45
Dummy	75	75	---
Max. Ballast	70	80	200
Gross Static	775 ± 25	895 ± 25	2000 ± 45
DIMENSIONS (cm)			
Wheelbase	230 ± 10	230 ± 10	335 ± 25
Front Overhang	75 ± 10	75 ± 10	80 ± 10
Overall Length	370 ± 20	370 ± 20	535 ± 25
Track Width ^b	135 ± 10	135 ± 10	165 ± 15
CENTER OF MASS LOCATION^a (cm)			
Aft of Front Axle	80 ± 15	80 ± 15	140 ± 15
Above Ground	55 ± 5	55 ± 5	70 ± 5
LOCATION OF ENGINE	Front	Front	Front
LOCATION OF DRIVE AXLE	Front	Front	Rear
TYPE OF TRANSMISSION	Manual or Automatic	Manual or Automatic	Manual or Automatic

^a For "test inertial" mass

^b Average of front and rear axles

For tests with the 2000P vehicle, the supporting truck should be placed on a clean, dry, paved surface. Asphaltic or portland cement concrete surfaces are recommended. Conditions such as a polished surface or a bleeding asphaltic surface that could lower available tire-pavement friction should be avoided.

For tests with the 2000P vehicle, the supporting truck should be in second gear with park brakes on. Front tires should have no steering angle, that is, they should not be turned to the left or to the right.

2.4. TEST VEHICLES

2.4.1. Description of Test Vehicles

Impact performance of a highway safety feature may be evaluated by use of a commercially available, production model vehicle or by a validated surrogate vehicle. To date, with the exception of breakaway support structures, safety features have been evaluated by use of production model vehicles.

2.4.1.1 Production Model Test Vehicles

Recommended properties of production model test vehicles are given in Tables 2.1 and 2.2. Vehicles 700C and 820C are small cars, vehicle 2000P is a pickup truck, vehicle 8000S is a single-unit truck, vehicle 36000V is a tractor/van-type trailer unit, and 36000T is a tractor/tank trailer unit. Note that the

numeric portion of the test vehicle designation is the vehicle's mass in kilograms.

In general, any test vehicle should be in good condition and free of major body damage and missing structural parts (i.e., doors, windshield, hood, etc.). Special purpose vehicles are not generally acceptable because they do not possess suspension and handling characteristics found in typical vehicles. Any manufacturer-installed equipment (power brakes and steering, air conditioning, etc.) is permitted so long as the equipment is contained within the body shell. The vehicle fuel tank should be purged and the battery removed from remotely powered test vehicles to reduce exposure to needless hazards. The bumpers on vehicles 700C, 820C, and 2000P should be standard equipment and unmodified for the test; configuration and height above grade should be reported. Tire size should be in accordance with the manufacturer's suggested size for each respective test vehicle. Highway, all season tires should be used on test vehicles 700C, 820C, and 2000P; mud or snow tires should not be used.

It is recommended the 700C vehicle be selected from one of the top two models, in terms of sales for the given model year, for cars with a curb mass of approximately 750 kg or less. It is recommended that the 820C vehicle be selected from one of the top two models, in terms of sales for the given model year, for cars with a curb mass in the 750 kg to 845 kg range. Car sales data may be obtained from the annual "Market Data Book," *Automotive News*, or "Automotive Year Book," *Wards Reports, Inc.* Reference should be made to the commentary for further discussions relative to the 820C vehicle.

TABLE 2.2 Recommended properties of 8000S, 36000V, and 36000T test vehicles

Property	8000S (Single-Unit Van Truck)	36000V (Tractor/Van Trailer)			36000T (Tractor/Tank Trailer)		
		Tractor ^a	Trailer ^b	Combination	Tractor ^a	Trailer ^b	Combination
Mass (kg)							
Curb	5,450 ± 450	N/S	N/S	13,200 ± 1,400	N/S	N/S	13,200 ± 1,400
Ballast ^d	As Needed	N/A	As Needed	N/A	N/A	As Needed	N/A
Test Inertial	8,000 ± 200	N/S	N/S	36,000 ± 500	N/S	N/S	36,000 ± 500
Dimensions (cm)							
Wheelbase	535 (max)	480 (max)	N/S	N/A	480 (max)	N/S	N/A
Overall Length	870 (max)	N/S	1,525 (max)	1,985 (max)	N/S	N/S	1,985 (max)
Trailer Overhang ^a	N/A	N/A	220 (max) ^c	N/A	N/A	185 (max)	N/A
Cargo Bed Height ^b (Above Ground)	130 ± 5	N/A	132 ± 5	N/A	N/A	N/A	N/A
Center of Mass Location (cm)							
Ballast ^d (Above Ground)	170 ± 5	N/A	185 ± 5	N/A	N/A	205 ± 10	N/S
Test Inertial (Above Ground)	125 ± 5	N/S	N/S	N/S	N/S	N/S	N/S

a. Distance from rearmost part of trailer to center of trailer tandems.

b. Without ballast

c. If trailer equipped with slide axies, they should be set at rearmost position.

d. See section 2.4.2.2 for recommended ballasting procedures.

e. It is preferable that the trailer structure be of the "semi-monoscope" type construction. It is preferable that a sliding undercarriage (slide axles) be used to attach the trailer tandems to the taller frame.

f. It is preferable that a gasoline tank with an elliptical cross section be used.

g. Tractor should be a cab-behind-engine model, not a cab-over-engine model.

N/A – Not Applicable. N/S-Not Specified

Although it may be possible to meet recommended properties of the 2000P vehicle with a $\frac{1}{2}$ -ton pickup, a $\frac{3}{4}$ -ton pickup is recommended. It should have a regular or conventional cab; it should not have an extended or "crew" cab. It should have a regular or conventional bed; it should not have a special bed such as a "Sportside," a "Stepside," or a "Flareside." It should have only a rear drive axle. It is acceptable for the pickup to have a heavy-duty suspension option as provided by the manufacturer. Special suspension systems that alter the as-manufactured center of-mass location are to be avoided.

Model year of the 700C, 820C, and 2000P vehicles should be within 6 years of the year of test unless otherwise specified by the user agency. Exceptions to the age limitations are acceptable if it can be demonstrated that key properties of the test vehicle are essentially the same as those of a vehicle meeting all above recommended requirements. Key properties include those given in Table 2.1 plus unspecified properties that may change with succeeding model years such as dynamic force-deformation properties of the bumper and frontal structure of the vehicle and vehicular profile as defined by bumper height, hood height, hood sweep, windshield sweep, and height of windshield.

Three heavy test vehicles are included in Table 2.2 along with recommended properties. Although tests have been conducted with each of these vehicles, experience accumulated to date is limited and insufficient to clearly establish appropriateness of these vehicles for testing safety features or to establish well defined specifications for these vehicles.

No age limit is specified for the heavy test vehicles. However, if feasible they should be of recent vintage. They should be representative of widely used designs. The bumper on the truck/tractor should be original equipment or one with minimal structural capacity. Large, stiff, custom-made bumpers should not be used.

The trailer for the 36000V test vehicle should have a semimonocoque structural design. It should have a sliding undercarriage (slide axles) to attach the trailer frame to the tandem wheels. These axles should not be altered in any way for the test.

2.4.1.2 Surrogate Test Vehicles

A surrogate test vehicle or device may be used in lieu of a production model test vehicle provided (1) it can be demonstrated that the surrogate possesses essential properties of the production model test vehicle it is intended to replicate and (2) the production model vehicle it is intended to replicate meets recommendations of Section 2.4.1.1. A method for identifying essential properties and for validating a surrogate device for evaluating breakaway supports is given in reference 2. Note, however, that at the time of this writing there was no widely accepted methodology whereby a surrogate device could be designed and validated to replicate a given vehicle impacting a given safety feature. In absence of such a methodology, determination of validity and relevance of a surrogate device must be made by the appropriate user agency, that is, the agency responsible for selection and installation of the safety feature being evaluated by the surrogate.

In recent years, two types of surrogate devices have been used in the evaluation of breakaway supports for luminaires and signs, namely, a four-wheeled bogie (2) and a pendulum (3). The bogie has been used as a surrogate for a small car and has been used

for both low- and high-speed tests. The pendulum has been used as a surrogate for a small car for low-speed impacts.

Current bogies do not have the capability to assess effects of test article contact with the roof, windshield, or undercarriage of a vehicle. As such, they should not be used when such contacts are anticipated. Previous testing has shown that features such as a mailbox, emergency call-box, and flashing lights placed on drums or barricades tend to separate from their support during a high-speed impact and thus have the potential for impacting and penetrating the windshield. Bogie tests in which these types of contact occur, or would occur if a production model vehicle had been used, should be repeated with a production model vehicle.

It is recommended that the surrogate be constructed to replicate properties of a specific production model vehicle as opposed to a generic vehicle. Acceptable production model vehicles that may be replicated are those meeting requirements of Section 2.4.1.1.

2.4.1.3 Truck Used in TMA Test

The truck or supporting vehicle to which an attenuator or crash cushion is attached for a TMA test should be representative of the type and mass (including typical cargo) of the vehicle commonly used in service. If different types and masses of vehicles are used, consideration should be given to conducting the recommended test series (see Section 3.2.4) using a vehicle at both the lower and upper extremes in terms of mass. In absence of a common support vehicle, it is recommended that TMA tests be conducted with a support vehicle having a test inertial mass of $9000 + 450$ kg.

It may be possible to extrapolate results of a TMA test for supporting vehicles of differing mass. However, at the time of this writing no known validated procedures exist to make such extrapolations.

2.4.2. Mass Properties

2.4.2.1. Test Vehicle

Vehicle mass properties are important factors in the performance of a highway safety feature. Properties of sprung and unsprung mass, curb mass, test inertial mass, dummy mass, ballast mass, and test equipment mass are normally considered in some aspect of vehicle testing. For this document, mass properties of most importance are:

1. *Curb mass-mass* of test vehicle in its standard manufacturer condition, in which all fluid reservoirs are filled and the vehicle contains no occupants and cargo. In general, curb mass of vehicles 700C, 820C, and 2000P should not vary significantly from test inertial mass.

2. *Test inertial mass-mass* of test vehicle (including sprung and unsprung mass) and all items including ballast and test equipment rigidly attached to the vehicle structure. Mass of dummies, irrespective of the degree of restraint, is not included in test inertial mass.

3. *Loose ballast mass-mass* of simulated, unrestrained cargo used in special tests to evaluate effects of loose cargo.

4. *Gross static mass-total* of test inertial and dummy masses. For special tests it is the sum of test inertial mass, dummy mass, and loose ballast mass.

5. *Dummy mass-mass* of surrogate occupant.

Test vehicles 700C, 820C, and 2000P should be selected so that minimal adjustments to the curb mass will be necessary to achieve the test inertial mass. With the exception of seats, spare tires, fuel tank, battery, fluids and optional equipment, components should not be removed from the vehicle to meet mass requirements.

2.4.2.2 Ballast

For vehicles 700C, 820C, and 2000P, fixed ballast may be added as necessary to bring test inertial mass within limits of Table 2.1. Total mass added should not exceed 10 percent of the nominal test inertial mass given in Table 2.2. Ballast may be added in the following manner:

700C and 820C Vehicles. Concrete or metal blocks may be placed in the passenger compartment and rigidly attached to the vehicle structure by metal straps or other devices capable of sustaining expected impact loads (if expected loads are unknown attachments may be designed for loads equal to a minimum of 20 times the blocks' mass). The ballast should be placed in a manner that will minimize changes to the location of the center of mass of the vehicle in its "curb mass" configuration, consistent with needs of test equipment and its placement.

2000P Vehicle. Concrete or metal blocks may be placed in the passenger compartment and rigidly attached to the vehicle structure by metal straps or other devices capable of sustaining expected impact loads (if expected loads are unknown, attachments may be designed for loads equal to a minimum of 20 times the blocks' mass). Ballast should be placed in a manner that will minimize changes to the location of the center of mass of the vehicle in its "curb mass" configuration, consistent with needs of test equipment and its placement. As an alternative, metal plates may be placed and rigidly attached to the bed of the pickup truck immediately aft of the passenger compartment by metal straps or other devices capable of sustaining expected impact loads. The vertical dimension (height) of the plates should not exceed 7.5 cm. The plates should be oriented symmetrically with respect to the fore-aft centerline of the vehicle and in a manner that will minimize changes to the position of the center of mass of the vehicle for its "curb mass" configuration.

For the 8000S, 36000V and 36000T vehicles, it will be necessary to add ballast to simulate cargo and to achieve recommended nominal test inertial mass given in Table 2.2. It is recommended this be done as follows:

8000S Vehicle. Typically, it will be necessary to add approximately 2600 kg of ballast to the 8000S vehicle to obtain the nominal test inertial mass given in Table 2.2. This can be achieved by sand bags on pallets, bales of hay, or other means. To the extent possible, the ballast should be uniformly distributed along the length and width of the van. The ballast should be firmly secured to prevent movement during and after impact.

36000V Vehicle. Typically, it will be necessary to add approximately 23,000 kg of ballast to the trailer of the 36000V vehicle to obtain nominal test inertial mass given in Table 2.2. This can be achieved by sand bags on pallets or other means. To the extent possible, the ballast should be uniformly distributed along the length and width of the trailer. The ballast should be firmly secured to prevent movement during and after impact.

36000T Vehicle. Water should be added to the tank trailer to achieve nominal test inertial mass given in Table 2.2. Most tank trailers are compartmentalized and, if all compartments are filled with water, the recommended test inertial mass may be exceeded. In such a case, it is recommended selected compartments *befilled* so as to provide an approximately uniform distribution of ballast along the length of the trailer and to provide the highest possible center of mass of the ballast.

Support Truck Used in TMA Test. Depending on the type of support truck used in a TMA test, it may be necessary to add ballast to achieve the desired test inertial mass. Necessary ballast should be firmly secured to prevent movement during and after impact.

2.4.3. Propulsion and Braking

The test vehicle may be pushed, towed, or self-powered to the programmed test speed. If pushed or towed, the prime mover should be disengaged prior to impact permitting the vehicle to be "free-wheeling" during and after the collision. For self powered vehicles, the ignition should be turned off just prior to impact. Application of brakes should be delayed as long as safely feasible to establish the unbraked runout trajectory. As a minimum, brakes should not be applied until the vehicle has traveled at least two vehicle lengths plus 25 m from the point of last contact with the test article. Position of the vehicle at the time of brake application should be reported for each test.

To a very limited extent, live drivers have been used to conduct crash tests when risks are believed to be very small. In those cases, the driver accelerates the vehicle to the desired impact speed and steers the vehicle into the test article or feature at the desired impact angle. Special precautions are usually taken to protect the driver from unexpected behavior of the vehicle or test article. However, experience has demonstrated that the vehicle or test article in even a seemingly simple test can respond in a totally unexpected manner. Therefore, unless risks are *known* to be extremely small or unless the test necessarily involves the effects of driver response (such as tests to evaluate driver response to edge-drop problems), use of a live driver is strongly discouraged.

2.4.4. Guidance

Method of guidance of the test vehicle prior to impact is optional, providing the guidance system or its components do not effect significant changes in the vehicle dynamics during and immediately after the collision. The steering wheel should not be constrained unless essential for test safety purposes. If the steering wheel is to be constrained, the nature of this constraint should be clearly documented.

2.5 SURROGATE OCCUPANTS

As discussed below, a surrogate occupant is recommended for use in certain tests to evaluate the added mass effect and/or to evaluate kinematics of the occupant. However, the *primary* measure of risk is determined by the hypothetical "flail space" model.

As discussed in Section 5.3, a dummy may be used to supplement other occupant risk measures; if this is desired, it is recommended the Hybrid III dummy be used. However, it must be noted that the Hybrid III dummy is valid for *frontal or head on impacts* only, that is, those in which dummy movement is essentially parallel to the longitudinal vehicular axis (x-axis as shown in Figure 4.6). There is no dummy capable of accurately simulating the kinetics and kinematics of an occupant for oblique movements, that is, those in which occupant movement has both x and y components. Oblique occupant movement typically occurs when the vehicle is redirected away from the feature being impacted, such as a longitudinal barrier. Instrumentation of the surrogate occupant is not recommended unless the Hybrid III dummy is used.

An anthropometric dummy, such as the Hybrid I or II dummy, or other means such as sand bags, a concrete block, and so on, may be used to simulate the added mass effect of an occupant. If sand bags are used, they should be packaged in cloth bags of sufficient strength to avoid rupture during the test. When used, a dummy should be restrained with the existing occupant restraint system in the test vehicle. When used, sand bags or concrete blocks should be restrained to prevent movement during impact. As stated in Table 2.1, the surrogate occupant should be representative of the 50th percentile male with a mass of approximately 75 kg.

With the exception of tests with the 700C and the 820C vehicles, use of a surrogate occupant is optional. For tests with the 700C and 820C vehicles, one surrogate occupant is specified

primarily to evaluate typical unsymmetrical vehicle mass distribution and its effect on vehicle stability since the dummy's mass is 8 to 10 percent of the vehicle's mass. If used for the added mass effect only, the surrogate occupant should be placed in either the driver's seat or the passenger's seat, whichever position contributes most to the vehicle's post-impact instability, or yawing moment on the vehicle. For example, in an off-center, head on impact into a terminal or a breakaway/yielding support, with impact on the left front of the vehicle, the surrogate occupant should be in the passenger's seat. If the instrumented Hybrid III dummy is used to assess occupant risk in a head-on impact, it should be placed in the front seat on the side nearest the impact point for off-center impacts, and placed in the driver's seat for centered impacts.

When a surrogate occupant or the Hybrid III dummy is used in the 2000P vehicle, placement and restraint condition should be as those for the 700C and 820C vehicles.

A dummy should also be used if there is a reasonable expectation that occupant/test article interaction will occur during or after impact, or both. For example, during an impact with a "tall" longitudinal barrier, the occupant's head may protrude through the side window and strike the barrier. The dummy should be placed either in the driver's seat or the passenger side of the front seat, whichever is nearest the impact point. An onboard camera should be used to record dummy movement when occupant/test article interaction is expected.

For vehicles 8000S, 36000V, and 36000T, when a dummy is used, it should be placed in the driver's seat and it should be restrained with the existing restraint system.

Experience gained from limited side impact tests clearly shows the vulnerability of an occupant on the impact side of the vehicle, due typically to large intrusions of the test article into the occupant compartment. Experience has also shown risks to an occupant in such a collision may be assessed by a valid side-impact dummy (74). Reference may be made to Appendix G for a methodology for side impact testing.

CHAPTER 3

TEST CONDITIONS

3.1 GENERAL

Guidelines are presented for the impact performance evaluation of various safety features. Individual tests are designed to evaluate one or more of the principal performance factors: structural adequacy, occupant risk, and post-impact behavior of vehicle. These evaluation criteria are presented in Chapter 5.

Depending on the feature being evaluated, there are up to six test levels that can be selected. In general, the lower test levels are applicable for evaluating features to be used on lower service level roadways and certain types of work zones while the higher test levels are applicable for evaluating features to be used on higher service level roadways or at locations that demand a special, high-performance safety feature. It will be noted that test levels 4 through 6 are applicable to longitudinal barriers only.

Note that the requirements of test level 3 are similar to those defined in the "Crash Test Conditions for Minimum Matrix" given in *NCHRP Report 230 (1)*. It is to this level that most crash-tested safety features in use on U.S. highways have been qualified. Since the issuance of *Report 230*, there has been a greater recognition of the merits of tailoring performance and cost of safety features to site requirements. This is the reason for the multiple test levels presented here. It is beyond the scope of this document to define warrants for the various test levels.

It is the responsibility of the user agency(s) to determine which of the test levels is most appropriate for a feature's intended application. Agencies should develop objective guidelines for use of roadway safety features, considering factors such as traffic conditions, site conditions, traffic volume and mix, and the cost effectiveness of candidate safety alternatives. However, it is anticipated that safety features qualified for test level 3 will remain acceptable for a wide range of high-speed arterial highways. Test level 2 qualified features are expected to be deemed acceptable for most local and collector roads and many work zones. Test level 1 qualified features are expected to be deemed acceptable for some work zones and very low-volume, low-speed local streets and highways. Applicability of test levels 4 through 6 will probably be determined by volume of truck and heavy vehicle traffic and/or the consequences of penetration beyond the longitudinal barrier.

Although tests with the 700C vehicle are desirable, they are optional because (1) this vehicular type represents only a very small portion of the vehicular mix and (2) there is no assurance that an existing feature will meet the recommended performance criteria or that new features can be found that will fully meet the recommended performance criteria for these tests. In the interim until sufficient testing experience is acquired with the 700C

type vehicle, the test article should perform acceptably with all appropriate tests using the 820C and 2000P type vehicles and preferably should perform acceptably during tests with the 700C type vehicle. It may be assumed that test articles performing acceptably with 700C and 2000P type vehicles will also perform acceptably with the 820C vehicle; thus, the 820C vehicle tests need not be performed.

It is important to note that tests recommended herein are based in large part on past experience. It is not possible to anticipate the form that new designs will take nor the critical impact conditions of these new designs. As such, the test matrices presented in this section must not be viewed as all-inclusive. When appropriate, the responsible agency should devise other critical test conditions consistent with the range of expected impact conditions. Also, if warranted, additional tests can be conducted to evaluate a feature for nonidealized conditions, such as longitudinal barrier with curvilinear alignment, the placement of a feature on nonlevel terrain, or the placement of a feature behind a curb.

It is not uncommon for a designer/tester to make design changes to a feature during the course of conducting the recommended test series or after successful completion of the test series. Changes are often made to improve performance or to reduce cost of the design or both. Questions then invariably arise as to the need to repeat any or all of the recommended tests. Good engineering judgment must be used in such instances. As a general rule, a test should be repeated if there is a reasonable uncertainty regarding the effect the change will have on the test.

Note that each test in a given matrix has a specific "test designation" of the form "i-jk." The "i" refers to the test level and "jk" refers to the test number. Test designations preceded by an "S" refer to tests with the optional 700C vehicle.

3.2 TEST MATRICES

3.2.1 Longitudinal Barriers

3.2.1.1 General

Recommended tests to evaluate longitudinal barriers for six test levels are presented in Table 3.1. Reference should be made to the Glossary for definitions of length of need (LON) and transitions. These guidelines are applicable to both permanent barriers and temporary barriers used in work or construction zones. However, except under very unusual conditions, a temporary barrier would not normally be designed for impact conditions greater than test level 3.

TABLE 3.1. Test matrix for longitudinal barriers

Test Level	Barrier Section	Test Designation	Impact Conditions ^c			Impact Point	Evaluation Criteria ^a (See Table 5.1)
			Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (deg)		
1	Length of Need	1-10	820C	50	20	(b)	A,D,F,H,I,(J),K,M
		S1-10 ^a	700C	50	20	(b)	A,D,F,H,I,(J),K,M
1-11		2000P	50	25	(b)	A,D,F,K,L,M	
	Transition	1-20 ^d	820C	50	20	(b)	A,D,F,H,I,(J),K,M
		S1-20 ^a	700C	50	20	(b)	A,D,F,H,I,(J),K,M
1-21		2000P	50	25	(b)	A,D,F,K,L,M	
2	Length of Need	2-10	820C	70	20	(b)	A,D,F,H,I,(J),K,M
		S2-10 ^a	700C	70	20	(b)	A,D,F,H,I,(J),K,M
2-11		2000P	70	25	(b)	A,D,F,K,L,M	
	Transition	2-20 ^d	820C	70	20	(b)	A,D,F,H,I,(J),K,M
		S2-20 ^a	700C	70	20	(b)	A,D,F,H,I,(J),K,M
2-21		2000P	70	25	(b)	A,D,F,K,L,M	
3 Basic Level	Length of Need	3-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S3-10 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
3-11		2000P	100	25	(b)	A,D,F,K,L,M	
	Transition	3-20 ^d	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S3-20 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
3-21		2000P	100	25	(b)	A,D,F,K,L,M	
4	Length of Need	4-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S4-10 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
4-11 ^d		2000P	100	25	(b)	A,D,F,K,L,M	
4-12		8000S	80	15	(b)	A,D,G,K,M	
	Transition	4-20 ^d	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S4-20 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
4-21 ^d		2000P	100	25	(b)	A,D,F,K,L,M	
4-22		8000S	80	15	(b)	A,D,G,K,M	
5	Length of Need	5-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S5-10 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
5-11 ^d		2000P	100	25	(b)	A,D,F,K,L,M	
5-12		36000V	80	15	(b)	A,D,G,K,M	
	Transition	5-20 ^d	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S5-20 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
5-21 ^d		2000P	100	25	(b)	A,D,F,K,L,M	
5-22		36000V	80	15	(b)	A,D,G,K,M	
6	Length of Need	6-10	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S6-10 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
6-11 ^d		2000P	100	25	(b)	A,D,F,K,L,M	
6-12		36000T	80	15	(b)	A,D,G,K,M	
	Transition	6-20 ^d	820C	100	20	(b)	A,D,F,H,I,(J),K,M
		S6-20 ^a	700C	100	20	(b)	A,D,F,H,I,(J),K,M
6-21 ^d		2000P	100	25	(b)	A,D,F,K,L,M	
6-22		36000T	80	15	(b)	A,D,G,K,M	

^aTest is optional. See Section 3.1.

^bSee Figure 3.1 for impact point.

^cSee Section 3.3.2 for tolerances on impact condition

^dTest may be optional. See Section 3.2.1.2.

^eCriteria in parenthesis are optional.

3.2.1.2 Description of Tests

Test 10

Test 10 is conducted for the LON section for all test levels. The purpose of this small car test is to evaluate the overall performance of the LON section in general, and occupant risks in particular.

Tests 11 and 21

Test 11 for the LON section and Test 21 for the transition section are conducted for test levels 1 through 3. They are intended to evaluate strength of the section in containing and redirecting the 2000P test vehicle. Tests 11 and 21 are optional for test levels 4, 5, and 6. They should be conducted if a reasonable uncertainty exists regarding impact performance of the system for these tests. It is recommended that results of Tests 12 and 22 be carefully examined prior to conducting Tests 11 and 21. Tests 12 and 22 will establish basic structural adequacy of the barrier. However, satisfactory performance for Tests 12 and 22 does not assure satisfactory performance for Tests 11 and 21. For example, there may be geometric incompatibilities between the barrier and the 2000P vehicle that could result in excessive snagging or pocketing.

Test 20

Test 20 for a transition section is an optional test to evaluate occupant risk and post-impact trajectory criteria for all test levels. It should be conducted if there is a reasonable uncertainty regarding the impact performance of the system for this test. Results of Test 21 should be carefully examined prior to conducting Test 20. Test 21 will establish the structural adequacy of the transition. However, satisfactory performance for Test 21 does not assure satisfactory performance for Test 20. For example, there may be geometric incompatibilities between the transition and the 820C vehicle which could cause a failure from excessive snagging or pocketing.

Tests 12 and 22

Test 12 for the LON section and Test 22 for the transition section are conducted for test levels 4, 5, and 6. They are intended to evaluate strength of the section in containing and redirecting the heavy test vehicles.

As noted in Figure 3.1, Section 3.4.2 contains guidance on determination of the critical impact point (CIP). As discussed therein, depending on barrier design, there may be two CIPs. For example, a bridge rail with a splice located between support posts may have two CIPs: one that would produce maximum loading on the splice and another that would have the greatest potential for causing wheel snagging or vehicular pocketing. As another example, a transition may have a CIP in the vicinity of the upstream end and another in the vicinity of the downstream end. Therefore, if one test cannot evaluate both points of concern, it may be necessary to conduct the relevant test(s) at both points of concern. See further discussion on this matter in Section 3.4.2.

3.2.2 Terminals and Crash Cushions

3.2.2.1 General

Recommended tests to evaluate terminals and crash cushions are presented in Table 3.2. Reference should be made to the Glossary for definitions of these features. These guidelines are applicable to both permanent features and temporary features used in work or construction zones. Note that impact performance requirements of a terminal and a redirective crash cushion are the same.

Impact performance requirements, and hence capabilities, of a nonredirective crash cushion are considerably less than those for a redirective crash cushion. A redirective crash cushion is subjected to more tests, and the requirements of those tests are more rigorous. For example, it is recommended that Test 38 be conducted at the critical impact point of the redirective crash cushion. A similar test would be difficult to pass for a nonredirective crash cushion. As a consequence, conditions or sites at which a nonredirective crash cushion can be used may be limited. It is the responsibility of the user agency to determine where features addressed in this document have application, including redirective and nonredirective crash cushions.

Reference is made herein to "gating" and "nongating" features or devices. A gating device is one designed to allow controlled penetration of the vehicle when impacted between the end and the beginning of the length of need (LON) of the device. The widely used breakaway cable terminal (BCT) is a gating device. A nongating device is designed to contain and redirect a vehicle when impacted downstream from the end of the device. A terminal or crash cushion with redirection capabilities along its entire length is a nongating device.

3.2.2.2 Description of Tests

Following is a description of each test. Reference should be made to Figures 3.2 and 3.3 for vehicle/test article orientation at impact.

Tests 30 and 40

These tests are conducted with the vehicle approaching parallel to the roadway, with impact to the left or right of the vehicle's centerline. They are intended primarily to evaluate occupant risk and vehicle trajectory criteria. The vehicle should be offset to the most critical side, that is, the side which will result in the greatest occupant risk during and subsequent to impact, recognizing the direction the vehicle will tend to roll, pitch, and yaw subsequent to impact. If the impact is to the right of the vehicle's centerline, the vehicle will tend to rotate clockwise (as viewed from above) or counterclockwise if the impact is to the left. It may also roll and pitch depending on the geometry and impact behavior of the test article.

Tests 31 and 41

These tests are conducted with the vehicle approaching parallel to the roadway with impact at the vehicle's centerline. For a device designed to decelerate a vehicle to a stop, these tests are intended to evaluate the capacity of the device to

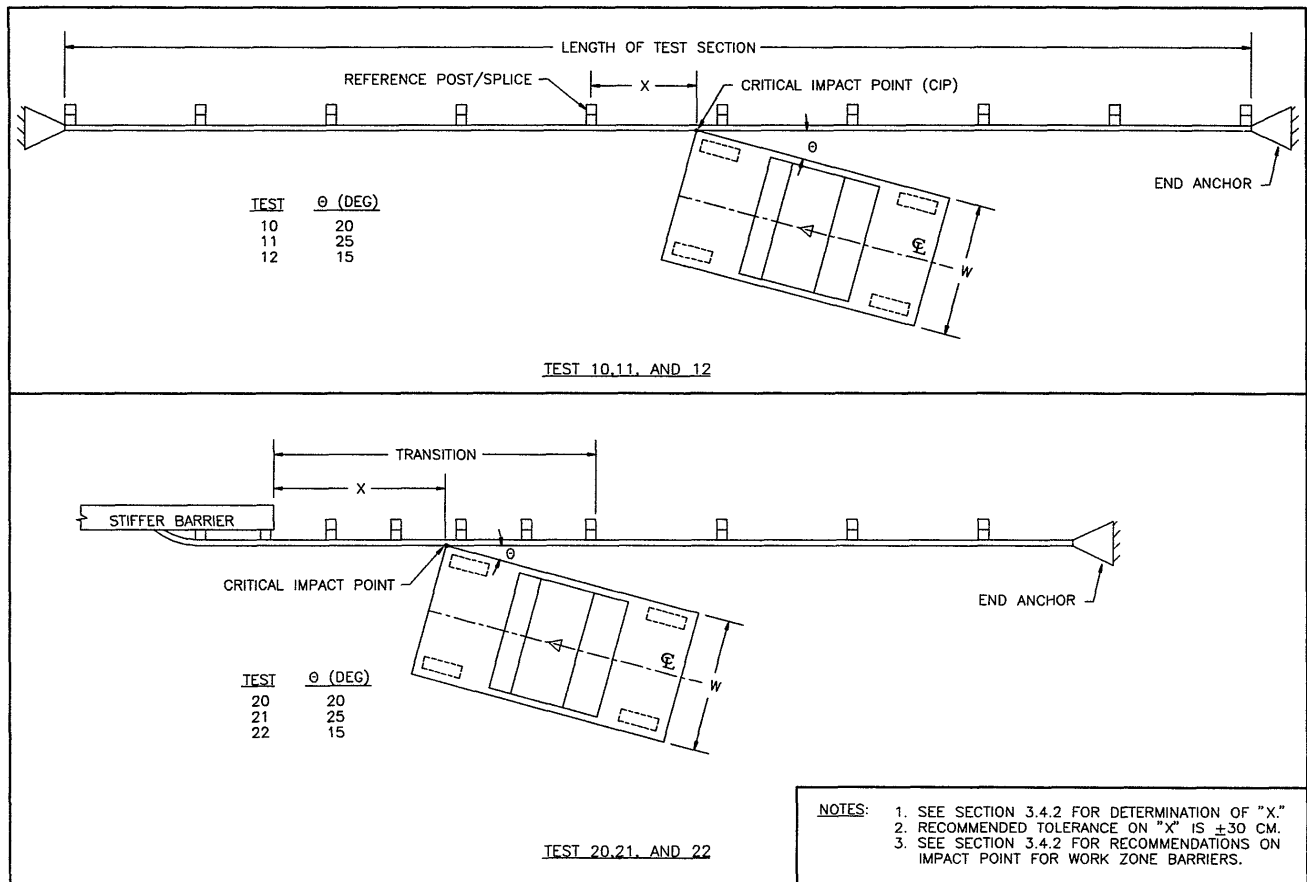


Figure 3.1. Impact conditions for longitudinal barrier tests.

absorb the kinetic energy of the 2000P vehicle (structural adequacy criteria) in a safe manner (occupant risk criteria). For other types of devices these tests are intended primarily to evaluate occupant risk and vehicle trajectory criteria.

Tests 32 and 33

Tests 32 and 33 are intended primarily to evaluate occupant risk and vehicle trajectory criteria. For some devices, it may be possible to demonstrate through engineering analysis, with a high degree of confidence, that Tests 32 and 33 are less severe than Tests 30 and 31. For example, in all probability Tests 32 and 33 would be less severe than Tests 30 and 31, respectively, for the breakaway cable terminal (BCT) for W-beam guardrail; the BCT is a gating device. In such cases, Tests 32 and 33 may be optional. However, Tests 32 and 33 should be conducted for a gating device if there is a reasonable uncertainty about the impact performance of the system for these tests.

Tests 34 and 35

These tests are applicable to gating devices only. In Test 34, impact should be at a CIP (see definition in Glossary) between the end of the device and the beginning of the LON.

Whereas definitive criteria are presented in Section 3.4.3 for estimating the CIP for selected devices, no such criteria are available for this particular application. Therefore, selection of the CIP for Test 34 should be based on test experience with similar devices, computer simulation if possible, and judgment. In selecting the CIP, consideration should not only be given to the point with the greatest potential for causing snagging or pocketing but also the point with the greatest potential for producing vehicular overturn. For example, in testing a sloped-end terminal, vehicular stability is the primary concern, not snagging or pocketing, and the CIP may not be midway between the end of the terminal and the beginning of the LON. In the absence of a determinable CIP, Test 34 may be conducted with the initial impact point midway between the end of the device and the beginning of the LON. Test 34 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. Test 35 is intended primarily to evaluate the ability of the device to contain and redirect (structural adequacy criteria) the 2000P vehicle within vehicle trajectory criteria at the beginning of the LON.

Tests 36, 37, and 38

These tests are applicable to nongating devices only. In Tests 36 and 37, the impact point should be at the end of the

TABLE 3.2. Test matrix for terminals and crash cushions

Test Level	Feature	Feature Type ^d	Test Designation	Impact Conditions ^e			Impact Point	Evaluation Criteria ^g (See Table 5.1)
				Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (deg)		
1	Terminals and Redirective Crash Cushions	G/NG	1-30	820C	50	0	(b,e)	C,D,G,H,I,(J),K,N
		G/NG	S1-30 ^a	700C	50	0	(b,e)	C,D,G,H,I,(J),K,N
		G/NG	1-31	2000P	50	0	(b)	C,D,G,H,I,(J),K,N
		G/NG	1-32	820C	50	15	(b)	C,D,G,H,I,(J),K,N
		G/NG	S1-32 ^a	700C	50	15	(b)	C,D,G,H,I,(J),K,N
		G/NG	1-33	2000P	50	15	(b)	C,D,G,H,I,(J),K,N
		G	1-34	820C	50	15	(b,e)	C,D,G,H,I,(J),K,N
		G	S1-34 ^a	700C	50	15	(b,e)	C,D,G,H,I,(J),K,N
		G	1-35	2000P	50	20	(b)	A,D,G,K,L,M
		NG	1-36	820C	50	15	(b)	A,D,G,H,I,(J),K,M
		NG	S1-36 ^a	700C	50	15	(b)	A,D,G,H,I,(J),K,M
		NG	1-37	2000P	50	20	(b)	A,D,G,K,L,M
		NG	1-38	2000P	50	20	(b)	A,D,G,K,L,M
		G/NG	1-39	2000P	50	20	(b)	C,D,G,K,L,M,N
	Nonredirective Crash Cushions ^f	G	1-40	820C	50	0	(e,h)	C,D,G,H,I,(J),K
		G	S1-40 ^a	700C	50	0	(e,h)	C,D,G,H,I,(J),K
		G	1-41	2000P	50	0	(h)	C,D,G,H,I,(J),K
		G	1-42	820C	50	15	(h)	C,D,G,H,I,(J),K,N
		G	S1-42 ^a	700C	50	15	(h)	C,D,G,H,I,(J),K,N
		G	1-43	2000P	50	15	(h)	C,D,G,H,I,(J),K,N
		G	1-44	2000P	50	20	(h)	C,D,G,K,N

^a Test is optional. See Section 3.1.

^b See Figure 3.2 for impact point.

^c See Section 3.3.3 for tolerances on impact conditions.

^d G/NG - Test applicable to gating and nongating devices.

G - Test applicable to gating device only.

NG - Test applicable to nongating device only.

^e See discussion in Section 3.2.2.2.

^f See discussion in Section 3.2.2.1 relative to nonredirective crash cushions.

^g Criteria in parenthesis are optional.

^h See Figure 3.3 for impact point.

terminal/crash cushion as illustrated in Figure 3.2. Tests 36 and 37 are intended to evaluate the redirection capability of the device for impacts at or near the nose of the device. Test 36 is intended primarily to evaluate occupant risk and vehicle trajectory criteria. Test 37 is intended primarily to evaluate structural adequacy and vehicle trajectory criteria. Test 37 will create maximum loading on the anchorage system at the nose of the device.

Test 38 differs in purpose from Test 37 in that it is intended to evaluate the potential for pocketing or snagging at the juncture with the object the device is shielding or terminating. The impact point should be selected to maximize the potential for pocketing or snagging. Guidelines for the CIP are given in Section 3.4.3. Test 38 may not be necessary if the lateral stiffness of the terminal/crash cushion is greater than that of the object the device is shielding or terminating. For example, this test would be necessary for a terminal/crash cushion used at the end of a rigid concrete barrier. It may not be necessary for a terminal/crash cushion used at the end of a semirigid guardrail barrier. Determination of need for this test should be based on test experience with similar devices, computer simulation if possible, and judgment.

Test 39

Test 39 is intended to evaluate the performance of a terminal/crash cushion for a "reverse" hit. For roadside or median applications, this test is recommended if the terminal/crash cushion will commonly be placed within the clear zone of opposing traffic.

Tests 42, 43, and 44

These tests are applicable to a nonredirective crash cushion only. Tests 42 and 43 are intended to evaluate occupant risk and vehicle trajectory criteria for both a small and a large passenger vehicle for an angled impact into the nose of the cushion. Test 44 is intended to evaluate the ability of the cushion to safely stop a large passenger vehicle prior to a life-threatening impact with the corner of the hazardous object being shielded.

3.2.2.3 Orientation of Terminal V Crash Cushion

Implied in the terminal/crash cushion orientations shown in Figures 3.2 and 3.3 is that the centerline of the feature in service

TABLE 3.2. (Continued)

Test Level	Feature	Feature Type ^d	Test Designation	Impact Conditions ^e			Impact Point	Evaluation Criteria ^a (See Table 5.1)
				Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (deg)		
2	Terminals and Redirective Crash Cushions	G/NG	2-30	820C	70	0	(b,e)	C,D,F,H,I,(J),K,N
		G/NG	S2-30 ^a	700C	70	0	(b,e)	C,D,F,H,I,(J),K,N
		G/NG	2-31	2000P	70	0	(b)	C,D,F,H,I,(J),K,N
		G/NG	2-32	820C	70	15	(b)	C,D,F,H,I,(J),K,N
		G/NG	S2-32 ^a	700C	70	15	(b)	C,D,F,H,I,(J),K,N
		G/NG	2-33	2000P	70	15	(b)	C,D,F,H,I,(J),K,N
		G	2-34	820C	70	15	(b,e)	C,D,F,H,I,(J),K,N
		G	S2-34 ^a	700C	70	15	(b,e)	C,D,F,H,I,(J),K,N
		G	2-35	2000P	70	20	(b)	A,D,F,K,L,M
		NG	2-36	820C	70	15	(b)	A,D,F,H,I,(J),K,M
		NG	S2-36 ^a	700C	70	15	(b)	A,D,F,H,I,(J),K,M
		NG	2-37	2000P	70	20	(b)	A,D,F,K,L,M
		NG	2-38	2000P	70	20	(b)	A,D,F,K,L,M
		G/NG	2-39	2000P	70	20	(b)	C,D,F,K,L,M,N
	Nonredirective Crash Cushions ^f	G	2-40	820C	70	0	(e,h)	C,D,F,H,I,(J),K
		G	S2-40 ^a	700C	70	0	(e,h)	C,D,F,H,I,(J),K
		G	2-41	2000P	70	0	(h)	C,D,F,H,I,(J),K
		G	2-42	820C	70	15	(h)	C,D,F,H,I,(J),K,N
		G	S2-42 ^a	700C	70	15	(h)	C,D,F,H,I,(J),K,N
		G	2-43	2000P	70	15	(h)	C,D,F,H,I,(J),K,N
	G	2-44	2000P	70	20	(h)	C,D,F,K,N	

^a Test is optional. See Section 3.1.

^b See Figure 3.2 for impact point.

^c See Section 3.3.3 for tolerances on impact conditions.

^d G/NG - Test applicable to gating and nongating devices.

G - Test applicable to gating device only.

NG - Test applicable to nongating device only.

^e See discussion in Section 3.2.2.2.

^f See discussion in Section 3.2.2.1 relative to nonredirective crash cushions.

^g Criteria in parenthesis are optional.

^h See Figure 3.3 for impact point.

will be parallel to the roadway and that the roadway is straight. It is likely that this will be the dominant orientation for most such features. However, if the feature will commonly be oriented otherwise, it should be so tested. In such a case the feature should be tested with its centerline oriented as it typically would be in service. Note that the impact angles recommended herein remain the same regardless of the orientation of the feature since they are implicitly measured with respect to the roadway tangent and not with respect to the feature. For example, Figure 3.4 illustrates the relative angle between a feature and the vehicle's approach for Test 31 (0-deg impact angle) for two different orientations of a feature. If the feature will typically be used in various orientations, worst-case test conditions should be selected within the recommended test matrices. For example, if a nongating, redirective crash cushion will typically be oriented in both configurations shown in Figure 3.4, redirective Tests 34, 35, and 36 should be conducted with the feature oriented as shown in configuration B.

3.2.2.4 Other Terminal/Crash Cushion Designs

Some current in-service terminals or crash cushions (such as short-radius, curved guardrail designs used in medians or at

bridge ends near an intersecting access road, or the "dragnet arrestor" system, or the gravel-bed attenuators for run-away trucks) may not be specifically addressed by the test matrices in Table 3.2. In such cases, the designer and test agency should devise tests to explore critical elements of the feature within the framework and intent of the recommended tests and evaluation criteria. Recommended test vehicles, impact speeds, and impact angles should be used with appropriate critical impact points.

3.2.3 Support Structures, Work Zone Traffic Control Devices, and Breakaway Utility Poles

3.2.3.1 General

Shown in Table 3.3 are recommended tests to evaluate support structures, work zone traffic control devices and breakaway utility poles. Reference should be made to the Glossary for definitions of these features.

Support structures include sign supports, mailbox supports, light poles or luminaire supports, and emergency call-box supports. The guidelines are applicable to permanent support structures as well as those used in construction or work zones. Fire hydrants are another "man-made" device commonly found within

TABLE 3.2. (Continued)

Test Level	Feature	Feature Type ^d	Test Designation	Impact Conditions ^c			Impact Point	Evaluation Criteria ^a (See Table 5.1)
				Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (deg)		
3 Basic Level	Terminals and Redirective Crash Cushions	G/NG	3-30	820C	100	0	(b,e)	C,D,F,H,I,(J),K,N
		G/NG	S3-30 ^a	700C	100	0	(b,e)	C,D,F,H,I,(J),K,N
		G/NG	3-31	2000P	100	0	(b)	C,D,F,H,I,(J),K,N
		G/NG	3-32	820C	100	15	(b)	C,D,F,H,I,(J),K,N
		G/NG	S3-32 ^a	700C	100	15	(b)	C,D,F,H,I,(J),K,N
		G/NG	3-33	2000P	100	15	(b)	C,D,F,H,I,(J),K,N
		G	3-34	820C	100	15	(b,e)	C,D,F,H,I,(J),K,N
		G	S3-34 ^a	700C	100	15	(b,e)	C,D,F,H,I,(J),K,N
		G	3-35	2000P	100	20	(b)	A,D,F,K,L,M
		NG	3-36	820C	100	15	(b)	A,D,F,H,I,(J),K,M
		NG	S3-36 ^a	700C	100	15	(b)	A,D,F,H,I,(J),K,M
		NG	3-37	2000P	100	20	(b)	A,D,F,K,L,M
		NG	3-38	2000P	100	20	(b)	A,D,F,K,L,M
	G/NG	3-39	2000P	100	20	(b)	C,D,F,K,L,M,N	
	Nonredirective Crash Cushions ^f	G	3-40	820C	100	0	(e,h)	C,D,F,H,I,(J),K
		G	S3-40 ^a	700C	100	0	(e,h)	C,D,F,H,I,(J),K
		G	3-41	2000P	100	0	(h)	C,D,F,H,I,(J),K
		G	3-42	820C	100	15	(h)	C,D,F,H,I,(J),K,N
		G	S3-42 ^a	700C	100	15	(h)	C,D,F,H,I,(J),K,N
		G	3-43	2000P	100	15	(h)	C,D,F,H,I,(J),K,N
G		3-44	2000P	100	20	(h)	C,D,F,K,N	

^a Test is optional. See Section 3.1.

^b See Figure 3.2 for impact point.

^c See Section 3.3.3 for tolerances on impact conditions.

^d G/NG - Test applicable to gating and nongating devices.

G - Test applicable to gating device only.

NG - Test applicable to nongating device only.

^e See discussion in Section 3.2.2.2.

^f See discussion in Section 3.2.2.1 relative to nonredirective crash cushions.

^g Criteria in parenthesis are optional.

^h See Figure 3.3 for impact point.

the clear zone of urban roadways. Although specific tests are not presented, when feasible, these devices should be designed to the same safety standards as support structures. Work zone traffic control devices include plastic drums, barricades, cones, chevron panels and their supports, and delineator posts and lights that may be attached to drums or barricades.

Note there is no test level 1 for these features. This is because, with few if any exceptions, features of this type that are cost effective for test levels 2 and 3 will also be cost effective for low-speed applications. For most sign supports and moderately sized luminaire poles, the low-speed test (35 km/h) is more critical than the high-speed test (100 km/h).

The following notes are applicable to tests in Table 3.3.

- A critical impact angle (CIA) should be determined and used for each test, consistent with the manner in which the feature will commonly be oriented in service with respect to traffic. For a given test and the attendant range of vehicular impact angles, the CIA is the angle within this range judged to have the greatest potential for causing a failure when the test is assessed by the recommended evaluation criteria. To determine the CIA, the in-service orientation of the support(s) and attendant breakaway feature(s) if used, the work zone traffic control

device(s), or the utility pole must first be established with respect to the normal direction of traffic. Then the CIA should be selected from a 0- to 20-deg impact angle envelope, as measured from the normal direction of traffic (see Figure 3.5). If the feature is commonly used at locations where impacts from a larger envelope are possible (such as at or near an intersection, or in a narrow median), it should be tested at the CIA within that envelope. If it is not apparent what the CIA is, it may be appropriate to test at each potential CIA. For example, if the feature can be struck from the front and rear, tests at CIAs consistent with these approach directions may be appropriate. (See discussion in Section 2.3.2.3 relative to special orientations for work zone traffic control devices.)

- For a single-support system, a single work zone traffic control device, or a utility pole, the center of the bumper should align with the vertical centerline of the feature. As an option, the left or right quarter point of the bumper may align with the vertical centerline of the device. Previous testing has shown that the offset option may be preferable in some cases because the same vehicle can be used to conduct both required tests (60 and 61) provided damage to the vehicle from the first test (usually the low-speed test) has no appreciable effect on impact performance of the vehicle/test article in the second test. How-

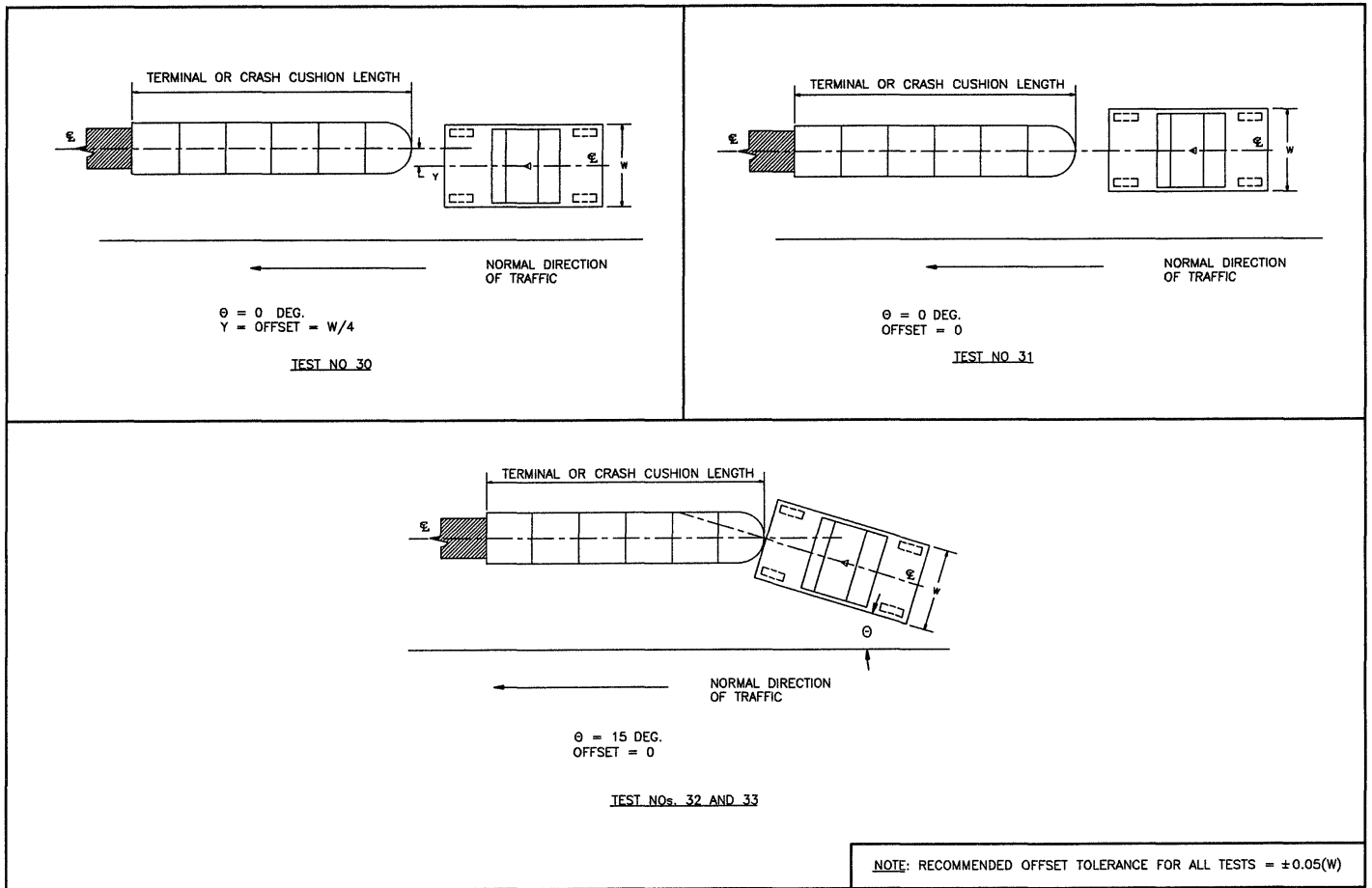


Figure 3.2. Impact conditions for terminal and redirective crash cushion tests.

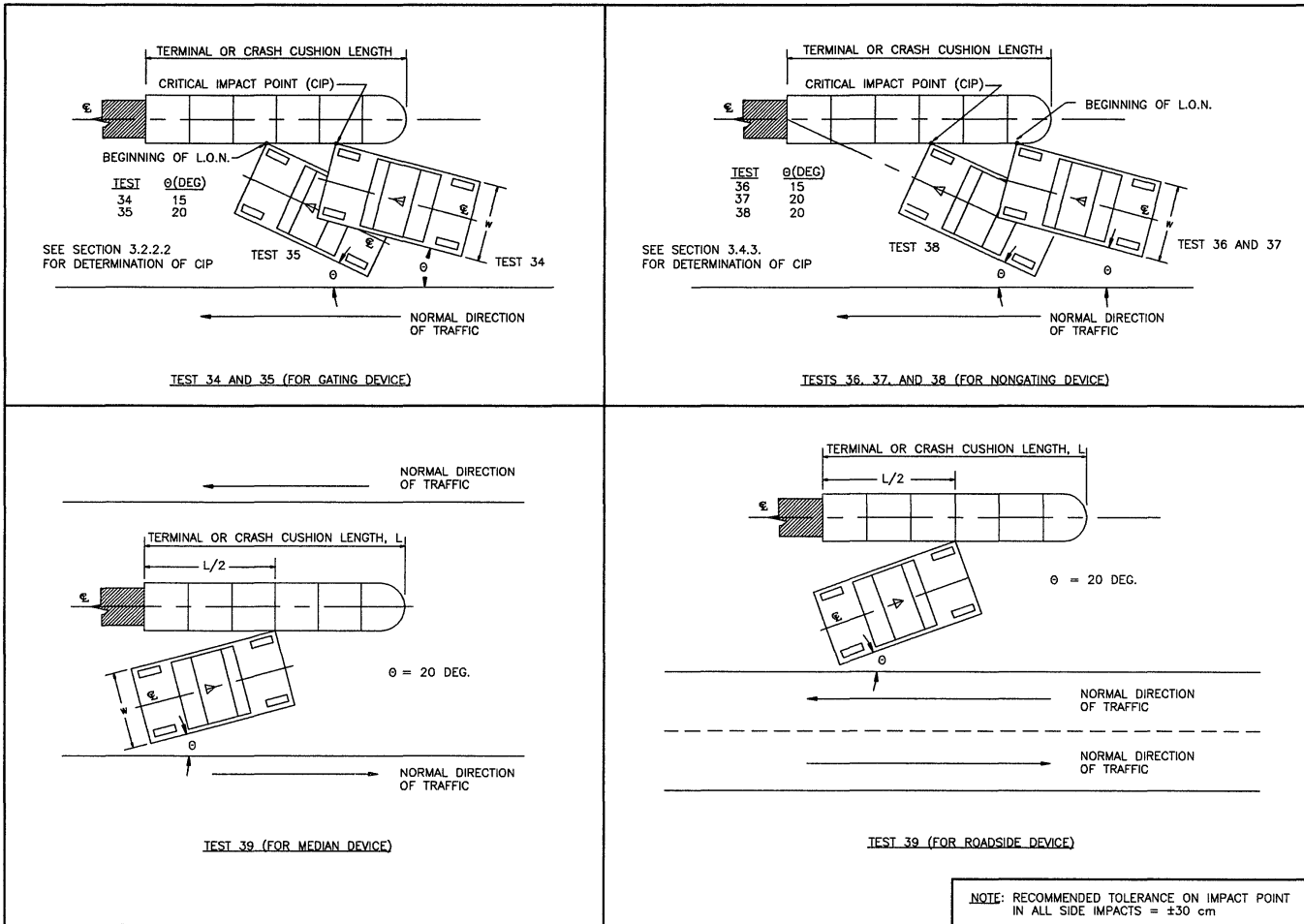


Figure 3.2. (continued).

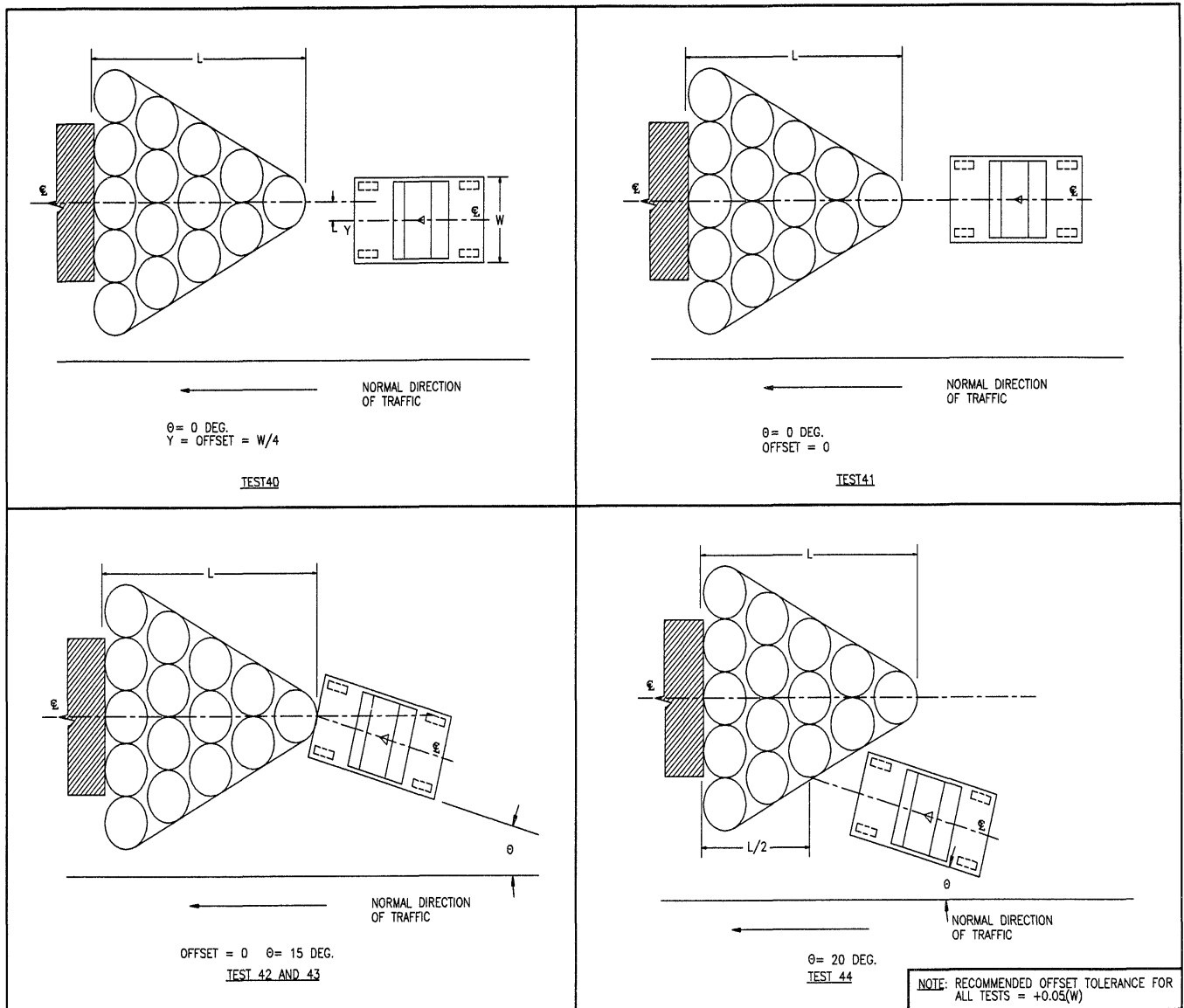


Figure 3.3. Impact conditions for nonredirective crash cushion tests.

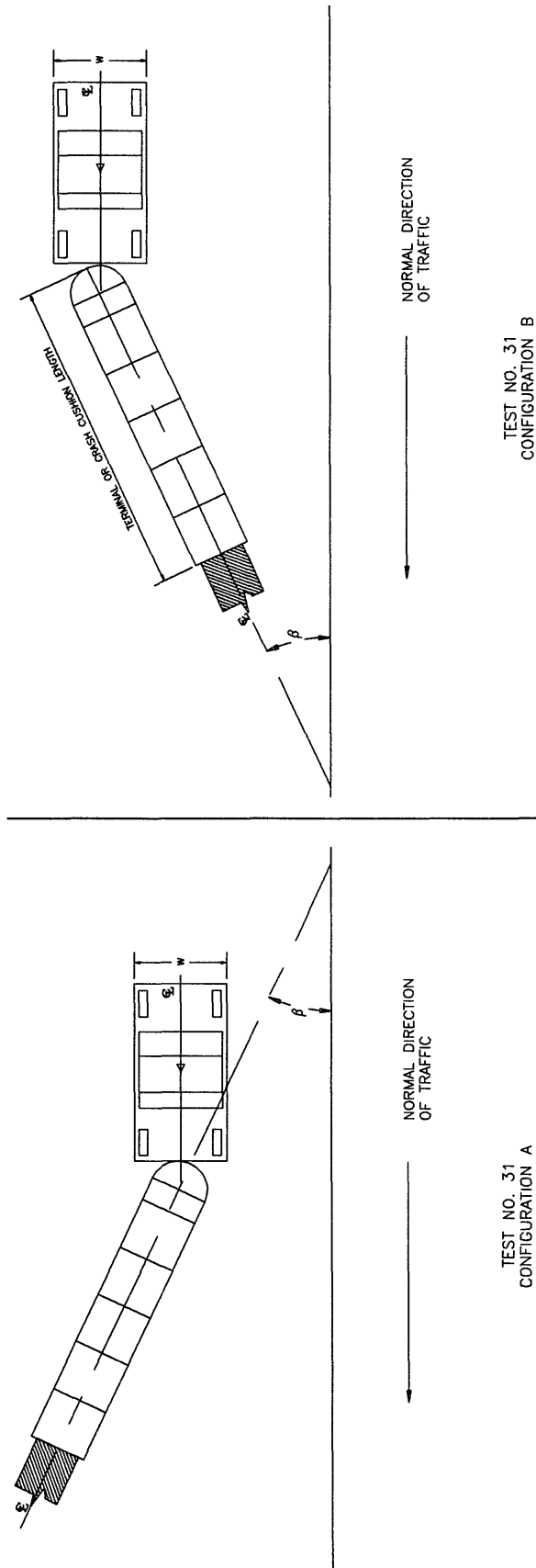


Figure 3.4. Atypical orientation of terminal or crash cushion.

ever, the potential for vehicular overturn will be greater in the high-speed test due to the yawing moment on the vehicle created by the offset impact.

- For a multiple - support device, the vehicle's approach path should be aligned so that the maximum number of supports are impacted unless the test is intended to evaluate other conditions.
- Recommended tolerance on the impact point is $\pm 0.05(W)$, where W is the width of the vehicle.

3.2.3.2 Description of Tests

Tests 60 and 61-Support Structures

Two tests are recommended for support structures for each test level using either the recommended 820C vehicle or the optional 700C vehicle: a low-speed test and a high-speed test. The low-speed test is generally intended to evaluate the breakaway, fracture, or yielding mechanism of the support whereas the high-speed test is intended to evaluate vehicle and test article trajectory. Occupant risk is of concern in both tests. If the primary concern regarding the impact behavior of a support system is penetration of the test article or parts thereof into the occupant compartment as opposed to occupant impact velocity and ridedown acceleration and/or vehicular stability, it may be preferable to use the 2000P vehicle in lieu of or in addition to the 820C vehicle. The choice will depend on the front profile of the two vehicles in relation to the geometry of the test article and elements thereon that could potentially penetrate the occupant compartment. In evaluating support structures for test level 3, tests should also be conducted at speeds between 35 and 100 km/h if there is a reasonable potential for such tests to be more critical than those recommended.

Tests 70 and 71-Work Zone Traffic Control Devices

Two tests are recommended for work zone traffic control devices for each test level using either the recommended 820C vehicle or the optional 700C vehicle: a low-speed test and a high-speed test. The low-speed test is generally intended to evaluate the breakaway, fracture, or yielding mechanism of the device whereas the high-speed test is intended to evaluate vehicular stability and test article trajectory. Occupant risk is of concern in both tests. Test 70 may be omitted when it can be clearly determined that Test 71 is more critical. For example, Test 71 will be more critical than Test 70 for work zone traffic control devices having a relatively small mass, such as plastic drums used as channelization devices, lightweight barricades, and so on. If the mass of a free-standing (resting on but not attached to ground or paved surface) work zone traffic control device is 45 kg or less, evaluation criteria H and I of Table 5.1 are optional. For a device with sand bags or other ballasts at its base (for stability), the mass of the ballast need not be added to the mass of the device provided the ballast effectively does not contribute to the change in the vehicle's velocity upon impact with the device. If the primary concern regarding the impact behavior of a traffic control device is penetration of the test article or parts thereof into the occupant compartment as

TABLE 3.3. Test matrix for support structures, work zone traffic control devices, and breakaway utility poles

Test Level	Feature	Test Designation	Impact Conditions ^c			Impact Point	Evaluation Criteria ^d (See Table 5.1)
			Vehicle	Nominal Speed (km/h)	Nominal Angle ^e , θ (deg)		
2	Support Structures	2-60	820C	35	0-20	(b)	B,D,F,H,I,(J),K,N
		S2-60 ^a	700C	35	0-20	(b)	B,D,F,H,I,(J),K,N
		2-61	820C	70	0-20	(b)	B,D,F,H,I,(J),K,N
		S2-61 ^a	700C	70	0-20	(b)	B,D,F,H,I,(J),K,N
	Work Zone Traffic Control Devices ^h	2-70 ^e	820C	35	0-20	(b)	B,D,E,F,H,I,(J),K,N
		S2-70 ^a	700C	35	0-20	(b)	B,D,E,F,H,I,(J),K,N
		2-71	820C	70	0-20	(b)	B,D,E,F,H,I,(J),K,N
		S2-71 ^a	700C	70	0-20	(b)	B,D,E,F,H,I,(J),K,N
	Breakaway Utility Poles ⁱ	2-80	820C	50	0-20	(b)	B,D,F,H,I,(J),K,N
		S2-80 ^a	700C	50	0-20	(b)	B,D,F,H,I,(J),K,N
		2-81	820C	70	0-20	(b)	B,D,F,H,I,(J),K,N
		S2-81 ^a	700C	70	0-20	(b)	B,D,F,H,I,(J),K,N
3 ^f Basic Level	Support Structures	3-60	820C	35	0-20	(b)	B,D,F,H,I,(J),K,N
		S3-60 ^a	700C	35	0-20	(b)	B,D,F,H,I,(J),K,N
		3-61	820C	100	0-20	(b)	B,D,F,H,I,(J),K,N
		S3-61 ^a	700C	100	0-20	(b)	B,D,F,H,I,(J),K,N
	Work Zone Traffic Control Devices ^h	3-70 ^e	820C	35	0-20	(b)	B,D,E,F,H,I,(J),K,N
		S3-70 ^{a,e}	700C	35	0-20	(b)	B,D,E,F,H,I,(J),K,N
		3-71	820C	100	0-20	(b)	B,D,E,F,H,I,(J),K,N
		S3-71 ^a	700C	100	0-20	(b)	B,D,E,F,H,I,(J),K,N
	Breakaway Utility Poles ⁱ	3-80	820C	50	0-20	(b)	B,D,F,H,I,(J),K,N
		S3-80 ^a	700C	50	0-20	(b)	B,D,F,H,I,(J),K,N
		3-81	820C	100	0-20	(b)	B,D,F,H,I,(J),K,N
		S3-81 ^a	700C	100	0-20	(b)	B,D,F,H,I,(J),K,N

^a Test is optional. See Section 3.1.

^b See Figure 3.5 for impact point.

^c See Section 3.3.4 for tolerances on impact conditions.

^d Criteria in parenthesis are optional.

^e See discussion in Section 3.2.3.2 relative to test 70.

^f See discussion in Section 3.2.3.2 relative to impact speeds for test level 3.

^g See discussion in Section 3.2.3.1 relative to the critical impact angle (CIA).

^h See discussion in Section 3.2.3.2 relative to evaluation criteria for work zone traffic control devices.

ⁱ See discussion in Section 3.2.3.2 relative to evaluation criteria for breakaway utility poles.

opposed to occupant impact velocity and ridedown acceleration and/or vehicular stability, it may be preferable to use the 2000P vehicle in lieu of or in addition to the 820C vehicle. The choice will depend on the front profile of the

two vehicles in relation to the geometry of the test article and elements thereon that could potentially penetrate the occupant compartment. In evaluating traffic control devices for test level 3, tests should also be conducted at speeds

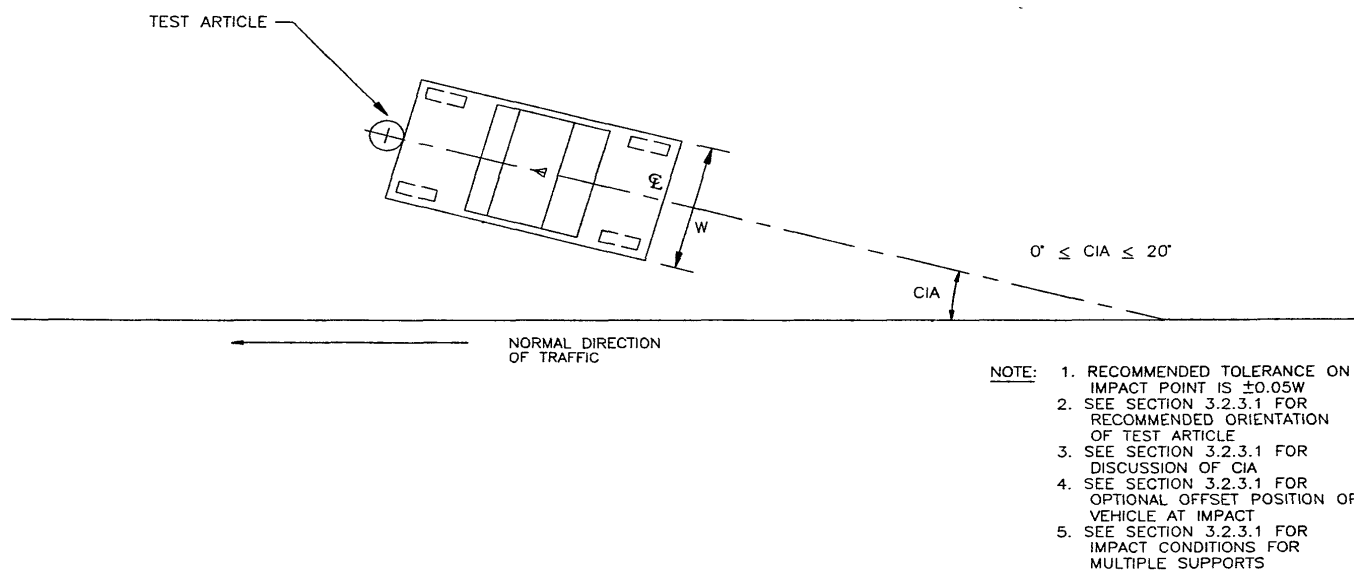


Figure 3.5. Impact conditions for single-support structures, work zone traffic control devices, and breakaway utility poles.

between 35 and 100 km/h if there is a reasonable potential for such tests to be more critical than those recommended.

Tests 80 and 81-Breakaway Utility Poles

Two tests are recommended for breakaway utility poles for each test level using either the recommended 820C vehicle or the optional 700C vehicle: a low-speed test and a high-speed test. The low-speed test is generally intended to evaluate the breakaway, fracture, or yielding mechanism of the support whereas the high-speed test is intended to evaluate vehicular stability and test article trajectory. Occupant risk is of concern in both tests. In evaluating breakaway utility poles for test level 3, tests should also be conducted at speeds between 50 and 100 km/h if there is a reasonable potential for such tests to be more critical than those recommended. Note that it is recommended that occupant impact velocities in a breakaway utility pole test not exceed values given in the upper part of criterion "H" of Table 5.1. However, it is preferable that they not exceed the values given in the lower part of criterion "H." (See discussion in Appendix A, Section A3.2.3.)

3.2.4 Truck-Mounted Attenuators (TMAs)

3.2.4.1 General

Recommended tests to evaluate TMAs are given in Table 3.4. Impact conditions for a TMA are shown in Figure 3.6. To date most, if not all, TMAs have been designed to meet performance requirements of test level 2 or requirements similar thereto. Test level 3 requirements are considerably more demanding and there is no assurance that a TMA can be designed to these requirements without adversely affecting other factors that must be considered

in the design and use of a TMA. Consequently, level 2 is considered the basic test level. Reference should be made to Section 2.3.2.4 concerning the manner in which the support truck is restrained or braked and to Section 2.4.1.3 for parameters of the support truck.

3.2.4.2 Test Descriptions

Tests 50 and 51

Test 50 is intended to evaluate risks to occupants of a small car impacting the TMA. Test 51 is intended to evaluate structural adequacy of the TMA, risks to occupants, and the roll-ahead distance of the supporting truck for impact with a heavy passenger vehicle. Roll-ahead distance is the distance the supporting truck moves after impact. Factors affecting this distance are discussed in Appendix A, Section A3.2.4. Roll-ahead distances are needed to select safe separation distances from the TMA vehicle and the workers it is intended to protect.

Tests 52 and 53 (optional)

Tests 52 and 53 are new tests and there is no assurance that current TMA designs can meet requirements of these tests. Moreover, there is no assurance that new TMA designs can be made to meet these test requirements without significant increases in cost or without detrimental effects on truck handling, TMA durability, or other operational considerations. For these reasons Tests 52 and 53 are optional. However, it should be a goal of developers and user agencies to develop a TMA capable of meeting requirements of these tests. Impact conditions for Tests 52 and 53 are believed to be representative of many collisions with TMAs.

TABLE 3.4. Test matrix for truck-mounted attenuators

Test Level	Test Designation	Impact Conditions ^a			Impact Point	Evaluation Criteria ^{a,g} (See Table 5.1)	EVALUATION CRITERIA ^{a,g} (See Table 5.1)
		Vehicle	Nominal Speed (km/h)	Nominal Angle, θ (deg)			
2 Basic Level	2-50	820C	70	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	S2-50 ^a	700C	70	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	2-51	2000P	70	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	2-52 ^h	2000P	70	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	2-53 ^h	2000P	70	10	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
3 ^d	3-50	820C	100	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	S3-50 ^a	700C	100	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	3-51	2000P	100	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	3-52 ^h	2000P	100	0	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K
	3-53 ^h	2000P	100	10	(b)	D,F,H,I,(J),K	C,D,F,I,(J),K

^a Test is optional. See Section 3.1.

^b See Figure 3.6 for impact point.

^c See Section 3.3.5 for tolerances on impact conditions. See Section 2.4.1.3 for recommendations relative to TMA support truck.

^d See discussion in Section 3.2.4.1 relative to test level 3.

^e For impacting vehicle and its occupants.

^f For supporting truck and its driver. See discussion in Section 5.3.

^g Criteria in parenthesis are optional.

^h Test is optional. See Section 3.2.4.1.

Note that recommended tests only address safety performance of a TMA due to vehicular collisions. Predictable and continued safe performance of a TMA will require consideration of other factors such as durability, mobility of supporting truck, road-induced vibrations, maintainability, influence of temperature variations, influence of moisture, and other factors. Reference 53 provides a synthesis of practices relevant to the selection and use of TMAs.

3.2.5 Roadside Geometric Features

Occasionally it may be desirable to experimentally evaluate the impact performance of roadside geometric features, such as safety treatments of drainage structures (e.g., sloped-end culverts with or without safety grates), driveway slopes, median crossover slopes, curbs, ditches, embankment side slopes, rock cuts, and discontinuities between the edge of the paved road surface and the shoulder. Because of the special nature of these features, it is not feasible to develop specific test matrices.

Crash test studies of geometric features have generally involved a combination of computer simulations coupled with limited full-scale crash tests (4-8). In most cases the HighwayVehicle-Object-Simulation Model (HVOSM) computer program

evaluate important parameters and to predict limits of impact performance of the feature. The accompanying crash test program is typically designed to verify and calibrate the results of the simulation study. This type of approach is usually necessitated by the number of variables that must normally be considered together with the limited number of tests that can be conducted. In the absence of a more rational procedure, a similar approach may be followed in future studies of these types of geometric features.

If feasible, these features should be designed and evaluated within the framework of one of the first three test levels for longitudinal barriers including test speeds and test vehicles. The recommended impact angles for longitudinal barrier tests may or may not be critical. It is possible that smaller angles will be more critical, something that can usually be determined by computer simulation. It is recommended that the impact angle not exceed 20 deg.

Previous studies (4) have shown that it is difficult from a practical and cost-effective standpoint to design certain geometric features, such as sloping culvert ends on driveways and the accompanying driveway slope, to meet evaluation criteria for high-speed (100 km/h) encroachments. Further studies are

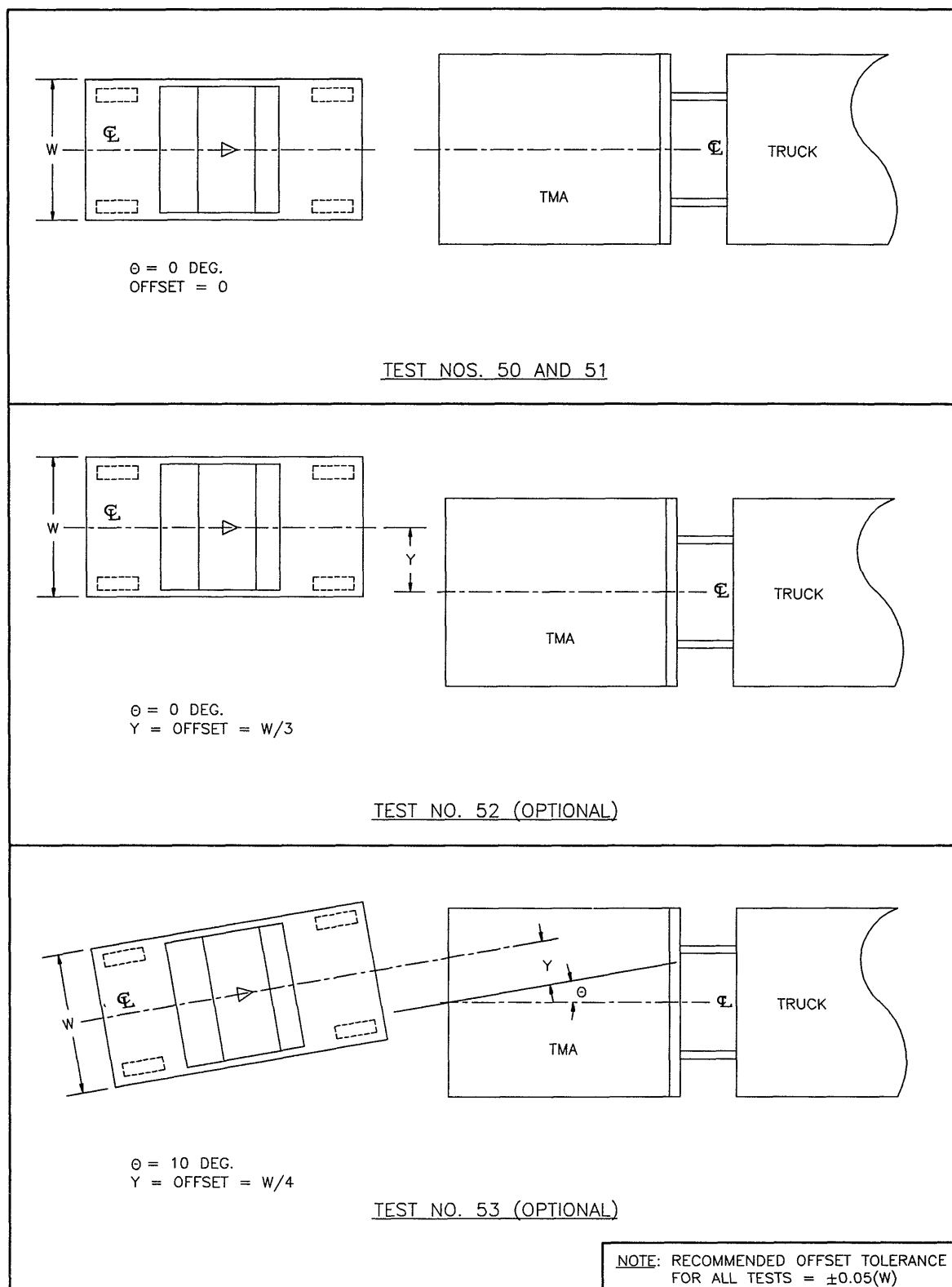


Figure 3.6. Impact conditions for a TMA.

TABLE 3.5. Impact speed and angle tolerances^a

Vehicle	Speed Tolerance (km/h)	Angle Tolerance (deg)
700C	± 4.0	± 1.5
820C	± 4.0	± 1.5
2000P	± 4.0	± 1.5
8000S	± 5.0	± 1.5
36000V	± 5.0	± 2.0
36000T	± 5.0	± 2.0

^a See Section 3.3.1 for discussion of composite tolerance limits for impact speed impact angle, and vehicle mass.

$$IS = \frac{1}{2} M(V \sin \Theta)^2$$

Where *IS* is the impact severity in joules (J), *M* is the test inertial mass of the vehicle in kilograms (kg), *V* is the impact speed in meters/second (m/s), and Θ is the impact angle in degrees (deg). For tests of redirection features, Θ is the impact angle; for all other tests, $\sin \Theta$ should be set to 1.

In theory, either of the three parameters *M*, *V*, and Θ can be adjusted, within reason, to achieve a desired *IS*. In practice, it is recommended that the test inertial mass of the vehicle be adjusted, as necessary, within the recommended tolerances to be reasonably close to the recommended nominal value. Assuming the test inertial mass is near the nominal value, either speed or angle or both can be adjusted to achieve the recommended *IS*. However, as a general rule, the target impact angle should not be adjusted because impact severity is extremely sensitive to this parameter. Thus, test speed should be the primary parameter adjusted, if necessary, to achieve the recommended *IS*.

The following sections give recommended limits on *IS* for given classes of features. Values given in the tables were computed as follows:

Nominal IS. Computed from Equation 3.1 with *M*, *V*, and Θ set

equal to nominal values as given in previous sections.

Suggested IS Tolerance. Two steps were used in computing negative and positive tolerances. For *negative tolerance*: (1) *IS* was computed from Equation 3.1 with *M* and Θ set equal to their nominal values and *V* set equal to its nominal value *minus* the tolerance given in Table 3.5, then (2) the suggested negative *IS* tolerance was determined by subtracting the nominal *IS* from the value of part 1. For *positive tolerance*: steps 1 and 2 were repeated except *V* was set equal to its nominal value *plus* the tolerance given in Table 3.5.

needed to examine and develop cost-effective safety treatments for geometric features.

A limited number of tests have been conducted on special roadway and roadside conditions, such as potholes and pavement/shoulder discontinuities (11-14). Typically, the approach taken in these types of studies involves a determination of limiting vehicular response parameters for a given roadway or roadside condition. For example, in evaluation of pavement edge discontinuities, live drivers are typically used. The typical test procedure is, in sequential order, to (a) drop the right side tires, or all four tires, of the vehicle just off the edge of the pavement, (b) begin a steer-back-to-the-road maneuver until the tires mount the pavement, and (c) input a corrective steer to avoid intrusion into an opposite lane. The path of the vehicle is observed and recorded. The procedure is repeated at increasing increments of vehicular speed until a speed is reached at which vehicular intrusions into an opposite lane occur or vehicular loss of control occurs.

To the extent appropriate and practical, evaluation criteria for a longitudinal barrier should be used to evaluate the impact performance of geometric features. See Section 5.6 for further discussions of this matter.

3.3 TOLERANCES ON IMPACT CONDITIONS

3.3.1 General

Impact conditions as defined by the mass, speed, and angle of the impacting vehicle are sometimes difficult to control and may vary slightly from recommended nominal values. The ability to control impact conditions decreases somewhat for the heavy vehicle tests, that is, those with the 8000S, 36000V, and 36000T vehicles. It is therefore necessary to establish reasonable limits or tolerances on impact conditions.

Recommended tolerances on the test inertial mass of test vehicles are given in Tables 2.1 and 2.2. A survey of testing agencies was conducted to examine "target" versus "actual" impact speed and angle for a number and variety of tests. Based on this survey, recommended tolerances for speed and angle are given in Table 3.5.

In addition to recommended tolerances on vehicular mass, speed, and angle, a composite tolerance limit is presented for the combined effects of the test parameters as determined by an impact severity expression:

3.3.2 Longitudinal Barriers

Table 3.6 lists nominal or target *IS* values and recommended tolerances for tests of longitudinal barriers.

For a longitudinal barrier test, it is preferable that the actual *IS* be equal to or greater than the target value. Furthermore, if the actual *IS* exceeds the positive tolerance and if test results meet recommended evaluation criteria, the test need not be repeated. In such a case, it is not necessary to meet the positive tolerance on speed or angle recommended in Table 3.5.

3.3.3 Terminals and Crash Cushions

Table 3.7 lists nominal or target *IS* values and recommended tolerances for tests of terminals and crash cushions.

For a terminal or crash cushion test, it is preferable that the actual *IS* be equal to or greater than the target value. Furthermore, if the actual *IS* exceeds the positive tolerance and if test results meet recommended evaluation criteria, the test need not be repeated. In such a case it is not necessary to meet the positive tolerance on speed or angle recommended in Table 3.5.

TABLE 3.6. Nominal impact severity values and tolerances for longitudinal barriers

Test Designation ^a	Nominal IS (kJ)	Suggested IS Tolerance (kJ)	
Test Level 1			
1-10, 1-20	9.3	-1.4	+1.5
S1-10, S1-20	7.9	-1.2	+1.3
1-11, 1-21	34.5	-5.3	+5.7
Test Level 2			
2-10, 2-20	18.1	-2.0	+2.1
S2-10, S2-20	15.5	-1.7	+1.8
2-11, 2-21	67.6	-7.5	+7.9
Test Level 3			
3-10, 3-20	37.0	-2.9	+3.0
S3-10, S3-20	31.6	-2.5	+2.6
3-11, 3-2	138.1	-10.8	+11.3
Test Level 4			
4-10, 4-20	37.0	-2.9	+3.0
S4-10, S4-20	31.6	-2.5	+2.6
4-11, 4-21	138.1	-10.8	+11.6
4-12, 4-22	132.5	-16.1	+17.1
Test Level 5			
5-10, 5-20	37.0	-2.9	+3.0
S5-10, S5-20	31.6	-2.5	+2.6
5-11, 5-21	138.1	-10.8	+11.3
5-12, 5-22	596.2	-72.3	+76.9
Test Level 6			
6-10, 6-20	37.0	-2.9	+3.0
S6-10, S6-20	31.6	-2.5	+2.6
6-11, 6-21	138.1	-10.8	+11.3
6-12, 6-22	596.2	-72.3	+76.9

^a See Table 3.1 for test descriptions.

3.3.4 Support Structures, Work Zone Traffic Control Devices, and Breakaway Utility Poles

Table 3.8 lists nominal or target IS values and recommended tolerances for tests of support structures, work zone traffic control devices, and breakaway utility poles.

For the *low-speed* test of a support structure, work zone traffic control device, or breakaway utility pole, it is preferable that the actual IS be equal to or less than the target value. However, it is recommended that the impact speed be within the recommended speed tolerances of Table 3.5 for the low-speed tests. For the *high-speed* test of a support structure, work zone traffic control device, or breakaway utility pole, it is preferable that the actual impact severity IS be equal to or greater than the target value. Furthermore, if the actual IS is greater than the recommended positive tolerance and if test results meet recommended evaluation criteria, the test need not be repeated. In such a case, it is not necessary to meet the positive tolerance on speed recommended in Table 3.5.

TABLE 3.7. Nominal impact severity values and tolerances for terminals and crash cushions

Test Designation ^a	Nominal IS (kJ)	Suggested IS Tolerance (kJ)	
Test Level 1			
1-30, 1-32, 1-40, 1-42	79.1	-12.1	+13.1
S1-30, S1-32, S1-40, S1-42	67.5	-10.4	+11.2
1-31, 1-33, 1-41, 1-43, 1-44	192.9	-29.6	+32.1
1-34, 1-36	5.3	-0.8	+0.9
S1-34, S1-36	4.5	-0.7	+0.8
1-35, 1-37, 1-38, 1-39	22.6	-3.5	+3.8
Test Level 2			
2-30, 2-32, 2-40, 2-42	154.9	-17.2	+18.2
S2-30, S2-32, S2-40, S2-42	132.3	-14.7	+15.5
2-31, 2-33, 2-41, 2-43, 2-44	377.9	-41.9	+44.4
2-34, 2-36	10.4	-1.2	+1.2
S2-34, S2-36	8.9	-1.0	+1.0
2-35, 2-37, 2-38, 2-39	44.2	-4.9	+5.2
Test Level 3			
3-30, 3-32, 3-40, 3-42	316.4	-24.8	+25.8
S3-30, S3-32, S3-40, S3-42	270.1	-21.2	+22.0
3-31, 3-33, 3-41, 3-43, 3-44	771.7	-60.4	+62.9
3-34, 3-36	21.2	-1.7	+1.7
S3-34, S3-36	18.1	-1.4	+1.5
3-35, 3-37, 3-38, 3-39	90.3	-7.1	+7.4

^a See Table 3.2 for test descriptions.

TABLE 3.8. Nominal impact severity values and tolerances for support structures, work zone traffic control devices, and breakaway utility poles

Test Designation ^a	Nominal IS (kJ)	Suggested IS Tolerance (kJ)	
Test Level 2			
2-60, 2-70	38.7	-8.3	+9.4
S2-60, S2-70	33.1	-7.1	+8.0
2-61, 2-71, 2-81	154.9	-17.2	+18.2
S2-61, S2-71, S2-81	132.3	-14.7	+15.5
2-80	79.1	-12.1	+13.1
S2-80	67.5	-10.4	+11.2
Test Level 3			
3-60, 3-70	38.7	-8.3	+9.4
S3-60, S3-70	33.1	-7.1	+8.0
3-61, 3-71, 3-81	316.4	-24.8	+25.8
S3-61, S3-71, S3-81	270.1	-21.2	+22.0
3-80	79.1	-12.1	+13.1
S3-80	67.5	-10.4	+11.2

^a See Table 3.3 for test descriptions.

TABLE 3.9. Nominal impact severity values for truck-mounted attenuators

Test Designation ^a	Nominal IS (kJ)	Suggested IS Tolerance (kJ)
Test Level 2		
2-50	154.9	-17.2 +18.2
S2-50	132.3	-14.7 +15.5
2-51, 2-52, 2-53	377.9	-41.9 +44.4
Test Level 3		
3-50	316.4	-24.8 +25.8
S3-50	270.1	-21.2 +22.0
3-51, 3-52, 3-53	771.7	-60.4 +62.9

^a See Table 3.4 for test descriptions.

3.3.5 Truck-Mounted Attenuators (TMAs)

Table 3.9 lists nominal or target *IS* values and recommended tolerances for tests of TMAs.

For a TMA, it is preferable that the actual *IS* be equal to or greater than the target value. Furthermore, if the actual *IS* exceeds the positive tolerance and if test results meet recommended evaluation criteria, the test need not be repeated. In such a case, it is not necessary to meet the positive tolerance on speed recommended in Section 3.3.1.

3.4 IMPACT POINT FOR REDIRECTIVE DEVICES

3.4.1 General

Impact point is the initial point of contact on a test article by the impacting test vehicle. It is generally known that the location of the initial impact point on a redirective device such as a longitudinal barrier, a terminal, or a redirective crash cushion can affect its safety performance. The potential for wheel snag, vehicular pocketing, and structural failure of the device depends on the initial impact point. To the extent possible, the initial impact point for a redirective device should be selected to establish a worst-case testing condition, that is, the critical impact point (CIP) or the point with the greatest potential for causing failure of the test, whether this be by excessive wheel snag, excessive pocketing, or structural failure of the device.

The Barrier VII simulation program has been used to select the CIP for longitudinal barrier tests (15) and it has been validated for this purpose. Although other barrier simulation programs such as GUARD and NARD (see Appendix D) may have the capability for identifying the CIP, they have not been validated for this application and are generally more difficult and costly to use.

When practical, it is recommended that Barrier VII be used to identify the CIP for a given set of test conditions (vehicle, barrier, and test speed and angle). The procedure described in Appendix A, Section A3.4.2, may be used for this purpose. If this is not

practical, the following guidelines, which were derived from the use of Barrier VII, may be used.

3.4.2 Longitudinal Barriers

In general there are two CIPs for a longitudinal barrier: one that produces the greatest potential for vehicular pocketing or wheel snagging and one that produces the greatest loading on a critical part of the barrier, such as at a rail splice. If the rail splice is located at a post, as is common in roadside and median barriers, both CIPs are coincident and one test can be used to evaluate all failure modes of concern. It is not uncommon in a bridge rail system for the splices to be located between posts. Fortunately, because the post spacing on most bridge rails is relatively small, all failure modes of concern can usually be evaluated with one test by placing a splice just upstream from the reference post (post from which the "x" distance is measured as described in the next section).

3.4.2.1 Tests with the 700C, 820C, and 2000P Vehicles

Computer simulations have demonstrated that critical impact points are controlled primarily by the post dynamic yield force per unit length of barrier, F_p , and the effective plastic moment of the barrier rail element(s), M_p (16). Post yield forces can be controlled by either post strength or soil confinement. F_p is calculated by dividing post dynamic yield force by post spacing. M_p is the effective plastic moment of all barrier rail elements. For a single rail barrier system, M_p is merely the plastic moment of the rail element. The effective plastic moment of a multiple rail system is the sum of the plastic moment of the highest beam and the plastic moments of lower beams reduced by a ratio of the heights of the highest and lower rail elements as given in Equation 3.2.

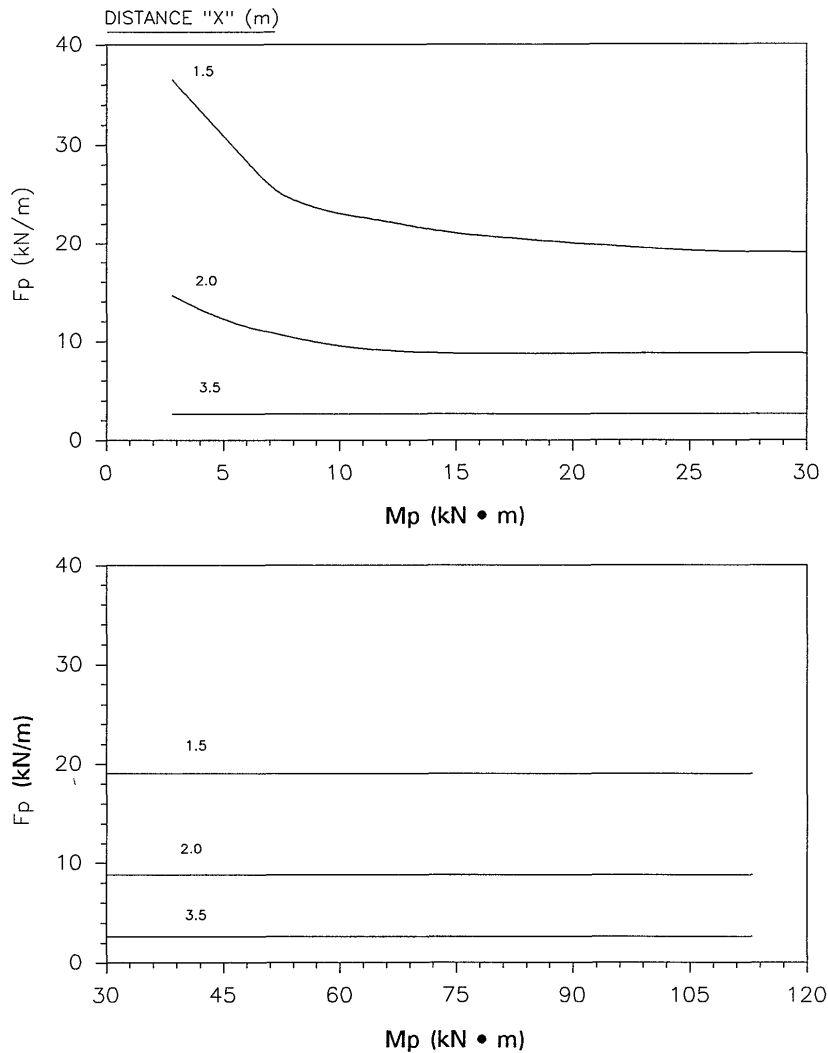
$$M_p = M_h + \sum M_i \times \left(\frac{H_i}{H_h} \right) \quad (3.2)$$

where:

- M_p = effective plastic moment of all barrier rail elements;
- M_h = plastic moment of highest rail element above ground or deck;
- M_i = plastic moment of a lower barrier rail element;
- H_i = height of a lower rail element; and
- H_h = height of highest rail element.

A more detailed discussion of F_p and M_p as well as tables of typical values can be found in Appendix A, Section A3.4.2.1.

Figures 3.7 through 3.10 are used to locate the critical impact point, as defined by the distance "x," for the length-of-need portion of flexible, longitudinal barriers (Tests 10 and 11) for a given test level. The figures show plots of the critical impact distance x for values of F_p and M_p for a given barrier system. Distances shown are measured upstream from the reference post/splice as shown in Figure 3.1. A rail splice should be located at



SEE FIGURE 3.1 FOR "X"

Figure 3.7. Critical impact point for Test 10, test levels 1 and 2.

or just upstream of the reference post, provided this is consistent with in-service practice. Interpolation may be used to find values of x for points between the curves and extrapolation may be used to find values of x for points above the upper curve or below the lower curve.

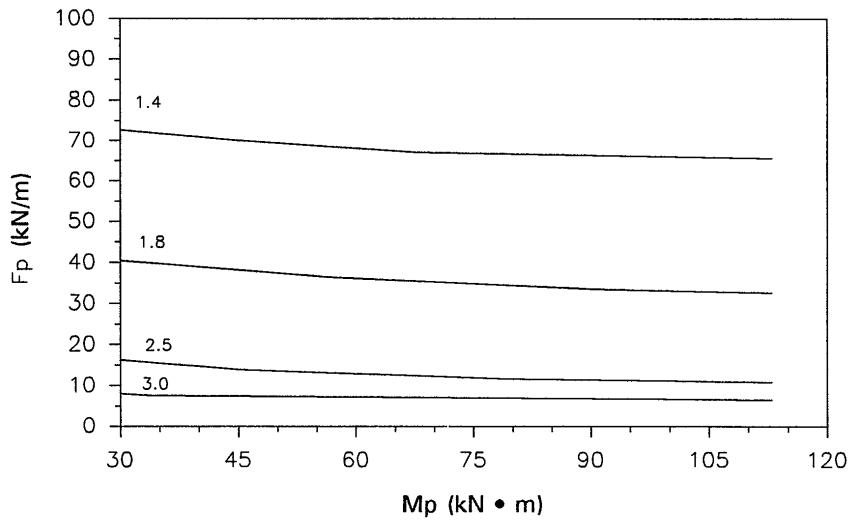
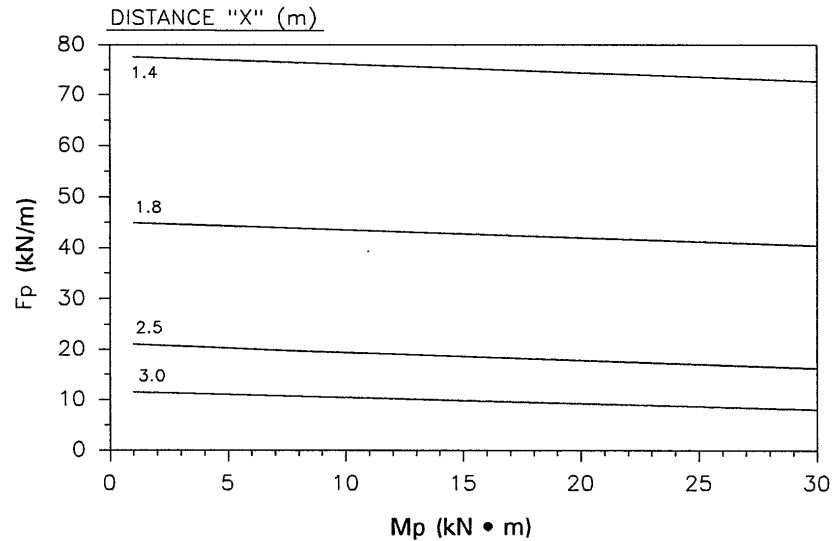
Figures 3.11 through 3.14 are used to locate the CIP for transitions between longitudinal barriers having different lateral stiffness (Tests 20 and 21) for a given test level. The figures show plots of the critical impact distance x for values of F_p and M_p for a given barrier system. Distances shown are measured upstream from the end of the stiffer system as shown in Figure 3.1. Interpolation may be used to find values of x for points between the curves and extrapolation may be used to find values of x for points above the upper curve or below the lower curve.

Properties of the more flexible barrier should be used for determining F_p and M_p . Note that Figures 3.11 through 3.14 were developed with a transition to a rigid barrier. When the stiffer barrier system is not rigid, the distance x will increase

slightly. However, crash testing and simulation have shown that this effect is relatively small and can usually be ignored. A more detailed discussion of the above procedures can be found in Appendix A, Section A3.4.2.1, and in reference 16.

When testing very stiff barrier systems (i.e., those that are essentially rigid such as concrete bridge rails), Table 3.10 may be used for x distances for the indicated tests. These numbers also represent minimum values for x distances. If extrapolations of curves shown in Figures 3.7 through 3.14 give CIP values lower than those shown in Table 3.10, " x " distances should be selected from Table 3.10.

Unlike beam and post systems, safety-shaped rigid barriers rely to a large extent on tire/barrier contact forces for redirecting impacting vehicles. As a result, critical impact distances for these barriers are somewhat different from the above values for rigid barriers. Table 3.11 shows CIPs for safety-shaped barrier impacts. Data shown in this table were derived from crash testing and simulation of impacts with both rigid and unanchored or



SEE FIGURE 3.1 FOR "X"

Figure 3.8. Critical impact point for Test 10, levels 3, 4, 5, and 6.

free-standing safety-shaped barrier systems. While testing and simulation results indicate these barriers exhibit slightly larger critical impact distances than their rigid counterparts, the differences are not significant. Therefore, Table 3.11 may be used for both rigid and free-standing safety-shaped barrier systems including precast concrete barriers used in work zones.

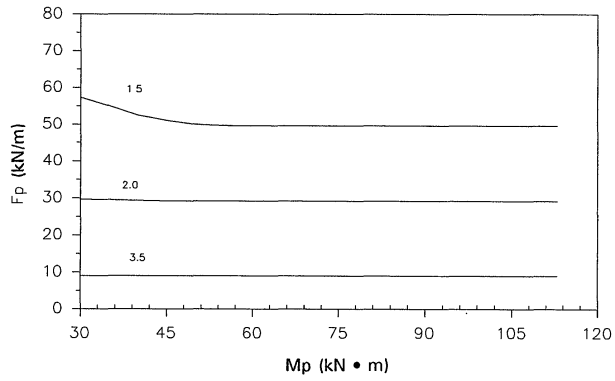
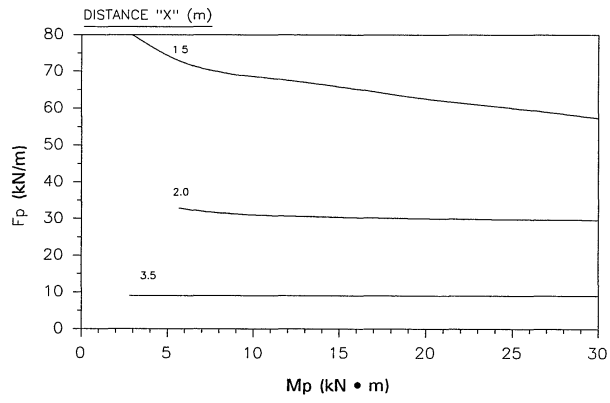
3.4.2.2 Tests with the 8000S, 36000V, and 36000T Vehicles

Large trucks do not exhibit the same sensitivity to wheel snag as automobiles and pickups. Therefore, the critical impact point for these vehicles should be chosen to maximize loading on critical barrier elements such as joints or splices. Because general procedures for determining critical impact points are not available for large trucks, these distances must be estimated from

crash testing of rigid barriers. Table 3.12 shows the critical distance x from impact point to the location of maximum lateral loading for a number of heavy vehicle crash tests (17). Note that a positive number indicates the maximum loading is *downstream* from the initial impact point and a negative number indicates the maximum loading is *upstream* from the initial impact point. Distances shown in this table were measured on a *rigid*, instrumented wall and, therefore, represent minimum values. Slightly larger distances can be expected for less rigid barriers as well as safety-shaped concrete barriers. Computer simulation is recommended to estimate the CIP for a truck test whenever practical.

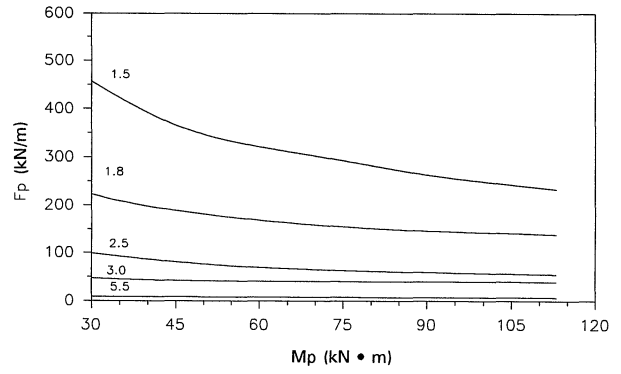
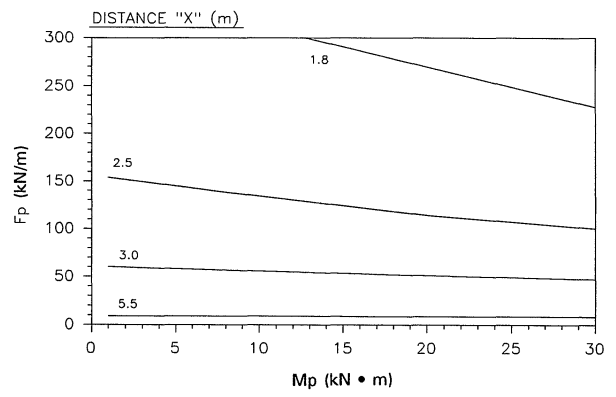
3.4.3 Terminals and Redirective Crash Cushions

Barrier terminals and redirective crash cushions are frequently used to prevent vehicles from impacting the end of a barrier or



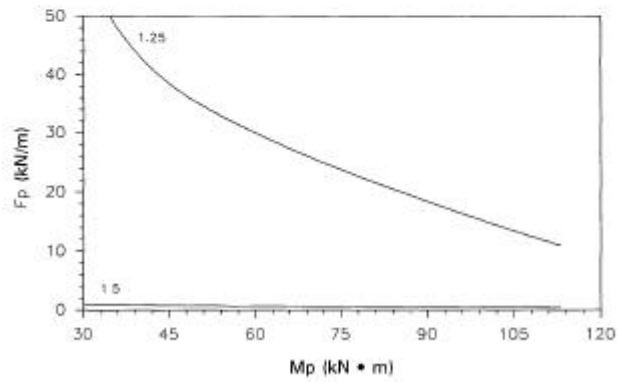
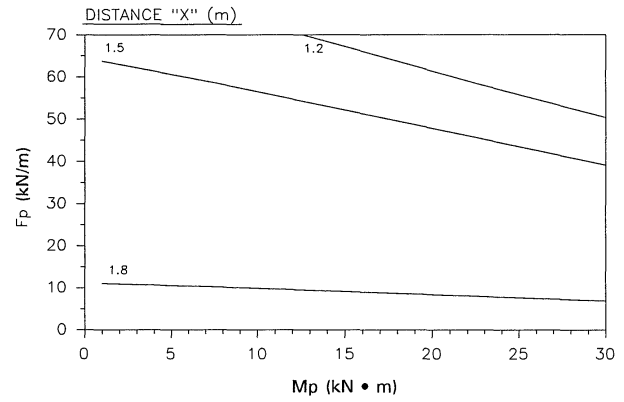
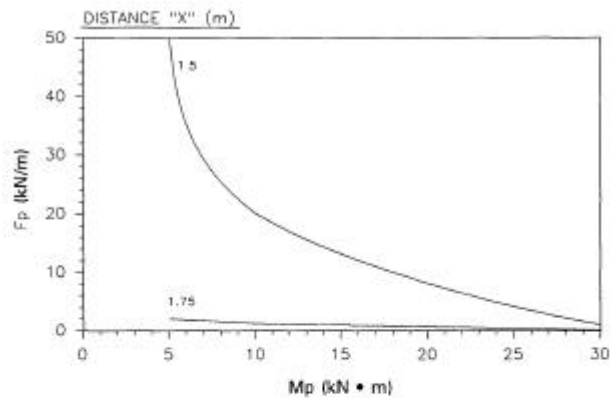
SEE FIGURE 3.1 FOR "X"

Figure 3.9. Critical impact point for Test 11, test levels 1 and 2.



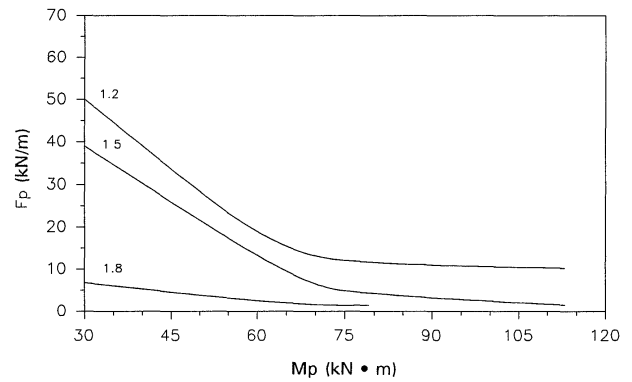
SEE FIGURE 3.1 FOR "X"

Figure 3.10. Critical impact point for Test 11, test levels 3, 4, 5, and 6.



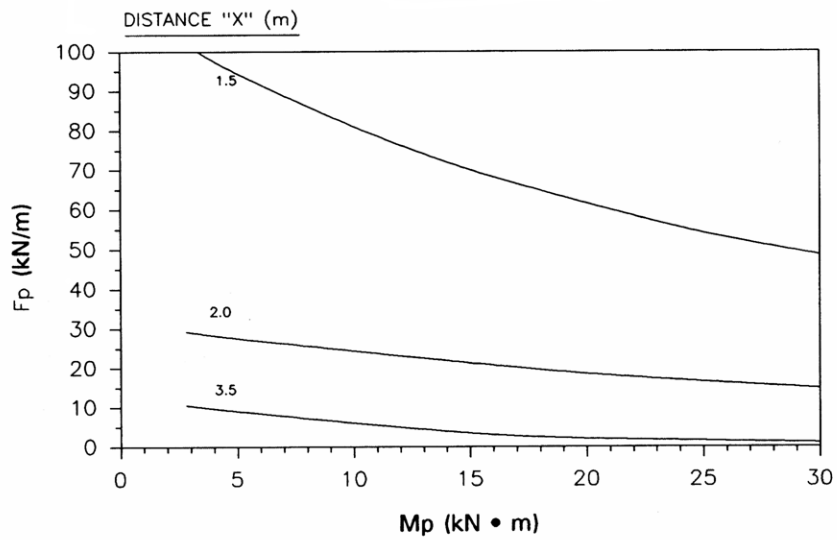
SEE FIGURE 3.1 FOR "X"

Figure 3.11. Critical impact point for Test 20, test levels 1 and 2.



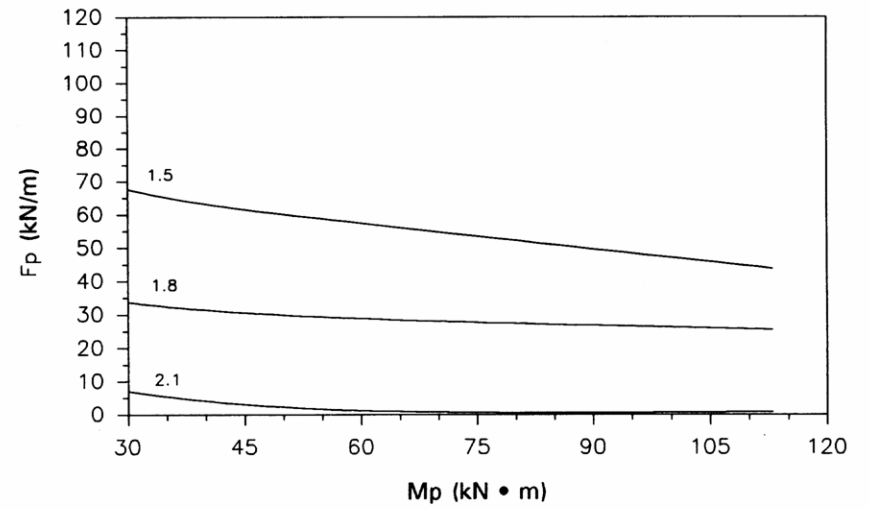
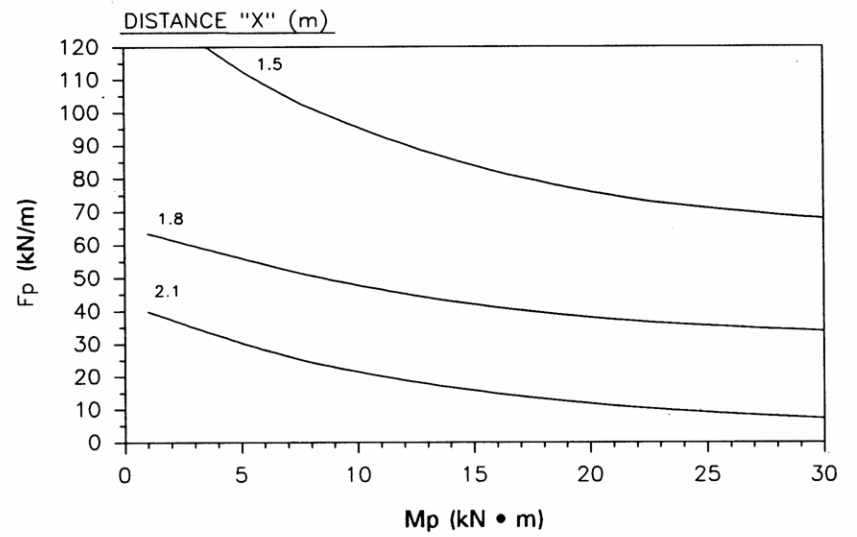
SEE FIGURE 3.1 FOR "X"

Figure 3.12. Critical impact point for Test 20, test levels 3, 4, 5, and 6.



SEE FIGURE 3.1 FOR "X"

Figure 3.13. Critical impact point for Test 21, test levels 1 and 2.



SEE FIGURE 3.1 FOR "X"

Figure 3.14. Critical impact point for Test 21, test levels 3, 4, 5, and 6.

TABLE 3.10. Critical impact point for rigid barrier tests with 700C, 820C, and 800S vehicles

Test Designation ^a	"x" Distance ^b (m)
1-10, S1-10, 2-10, S2-10	1.0
3-10, S3-10, 4-10, S4-10 5-10, S5-10, 6-10, S6-10	1.1
1-11, 2-11	0.8
3-11, 4-11, 5-11, 6-11	1.3

^a See Table 3.1 for test descriptions.

^b See Figure 3.1 for "x."

TABLE 3.11. Critical impact point for concrete safety-shaped barrier tests

Test Designation ^a	"x" Distance ^b (m)
1-10, S1-10, 2-10, S2-10	0.7
3-10, S3-10, 4-10, S4-10 5-10, S5-10, 6-10, S6-10	0.8
1-11, 2-11	0.8
3-11, 4-11, 5-11, 6-11	1.2

^a See Table 3.1 for test descriptions.

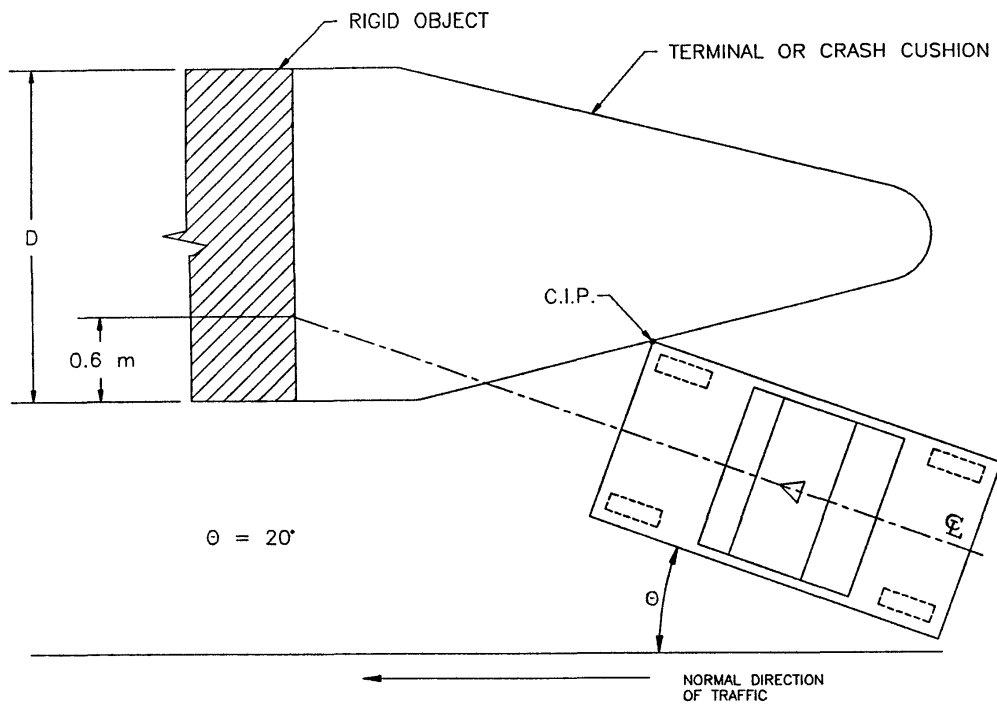
^b See Figure 3.1 for "x."

TABLE 3.12. Critical impact point for heavy vehicle tests

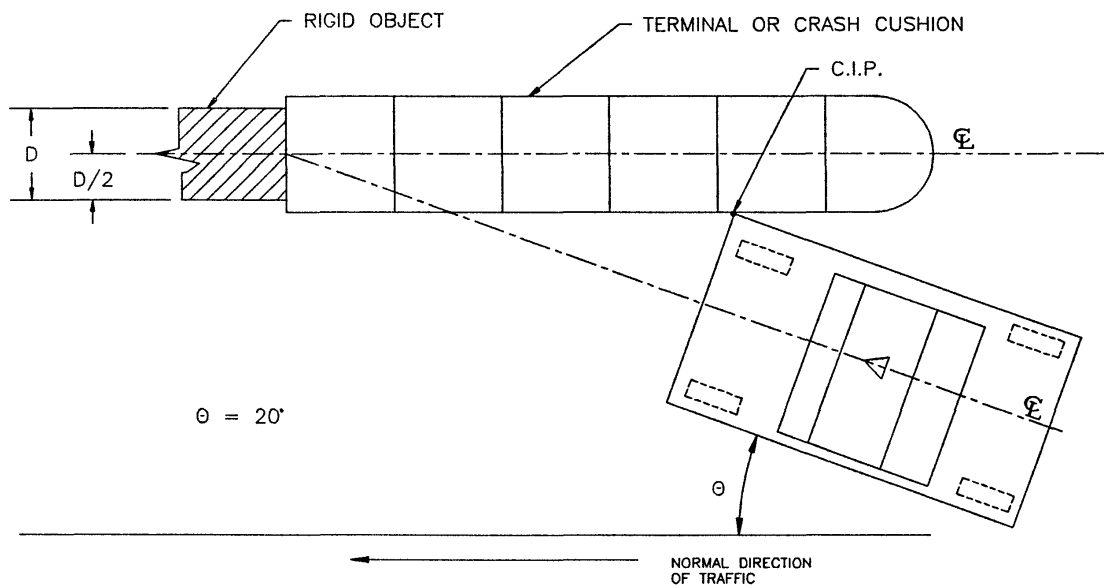
Test Designation ^a	"x" Distance ^b (m)
4-12	1.5
5-12	-0.3
6-12	0.6

^a See Table 3.1 for test descriptions.

^b See Figure 3.1 for "x."



TEST 38 FOR NONGATING DEVICE WHEN $D > 1.2$ m



TEST 38 FOR NONGATING DEVICE WHEN $D \leq 1.2$ m

Figure 3.15. Critical impact point for Test 38 of nongating device.

some other rigid obstacle. Proper performance of these systems requires redirection of vehicles impacting on the side of the feature. Although no studies have been conducted to identify critical impact points for such features, crash test experience has indicated that for a narrow rigid object the greatest potential for wheel snag or pocketing occurs when the center of the test vehicle is directed at the center of the rigid object. In the case of a very wide rigid object, the greatest potential for wheel snag or pocketing is believed to occur when the center of the vehicle is directed at a spot on the object approximately 0.6 m from the edge of the rigid object. These points are illustrated in Figure 3.15. In the absence of more definitive guidelines for determining the CIP for a terminal or a redirective crash cushion, the impact point for Test 38 may be determined as illustrated in Figure 3.15.

3.5 SIDE IMPACT TESTS

Previous testing guidelines for roadside safety features, as well as those presented herein, use a tracking test vehicle. As such, the vehicle approaches the test article with no appreciable yawing or sideslip motion and, hence, the rear tires essentially track the path of the front tires. However, a large percentage of errant vehicles leave the travelway and impact roadside features in a nontracking or yawed mode (18). Furthermore, the impact performance of a safety or geometric feature is more likely to be unacceptable for a nontracking or side impact than for a tracking impact, all other conditions being the same. Evidence to this effect can be found in the literature (7,19).

A limited number of tests have been conducted in recent years to evaluate side impacts into pole-type support structures (20). Unfortunately, as results of these tests show, it is not feasible to design most roadside safety and geometric features to satisfy current evaluation criteria for side impacts. Consequently, no recommendations are made relative to the impact performance of a safety feature for side impacts.

Risks to occupants in a side impact are high due in large part to very limited vehicular crashworthiness for side impacts. The relatively "soft" side structure of passenger vehicles, coupled with the close proximity of the occupants to the side structure, presents formidable occupant protection problems. Breakaway devices do not readily activate due to the softer side structure and due to the resultant impact force being applied at a higher point than for a head-on impact. Also, there is an increased propensity for overturn when the vehicle is in a nontracking mode.

Concurrent with the effort to prepare this report, an FHWA sponsored study was being conducted to examine the side impact problem and to develop tentative side impact test procedures for sign and luminaire support structures (21). Recommended test and evaluation procedures for side impact testing developed in the FHWA study are given in Appendix G. Until these or other guidelines are nationally accepted, developers of safety features for side impact capabilities may use the guidelines in Appendix G.

This discussion points to the need for further studies to (a) define the magnitude and nature of the nontracking impact problem and (b) develop strategies to mitigate the problem.

CHAPTER 4

DATA ACQUISITION

4.1 TYPICAL PARAMETERS

Proper documentation of a crash test involves three distinct phases. (1) Key properties of the test article and the test vehicle must be recorded in the pretest phase. (2) During the test itself, it is important that the dynamic behavior of the test article and the test vehicle be properly recorded. (3) Finally, it is essential that damage to the test article and test vehicle be documented in the post-test phase.

4.2 PRETEST PARAMETERS

In the pretest phase, the chief objective is to document properties of the test vehicle and the as-built test article. Use of photography is essential in this phase. Key parameters that should be documented in the pretest phase are given in the next section. These parameters are not necessarily all-inclusive and should be supplemented by other relevant parameters as necessary.

4.2.1 Test Vehicle

It is recommended that parameters identified in Figures 4.1 through 4.5 be measured and recorded for the respective test vehicles. It is also preferable that the parameters be recorded in the format shown to facilitate standard reporting among testing agencies. Pretest photographs of the exterior of the test vehicle as well as the occupant compartment of vehicles 700C, 820C, and 2000P should be made (see Section 4.4). Reference should be made to Section 4.3.3 for recommendations relative to accelerometer placement and documentation thereof. In absence of a more exact method, the procedure in reference 81 may be used to determine the center of mass location for two-axle vehicle.

In addition to the information of Figures 4.1 through 4.5, the use of ballasts in any of the test vehicles should be properly documented. This documentation includes ballast type, mass, location, center of mass, method by which it is secured, and photos of the ballast. Also, when feasible, the longitudinal and vertical position of the center of mass of the tractor and unballasted trailer for vehicles 36000V and 36000T should be measured and recorded.

In tests of longitudinal concrete barriers, some testing agencies have used chalk or paint on the sidewall of tires that contact the barrier. Different colored chalk or paint is used to determine length and height of each tire's contact with the barrier. This practice is acceptable provided that the chalk or paint does not appreciably alter the tire-barrier friction properties.

For a TMA test, the year, make, and model of the supporting truck should be documented. The ballast mass, test inertial mass

of the supporting truck, and the distribution of the test inertial mass between the front and rear axles should be recorded. The location and manner in which the ballast was secured should be documented. The manner in which the supporting truck was braked should also be documented. See Section 2.3.2.4 for recommendations relative to truck braking.

4.2.2 Test Article

4.2.2.1 General

For any test, the type of paving or soil surface on which the article is mounted and on which the pre-impact approach and post-impact trajectory of the vehicle takes place should be reported. Material specifications should refer to a nationally recognized standard such as ASTM, AASHTO, ACI, AISC, or AISI. The research report should document any pertinent details of the construction of the test article, including special equipment used, problems encountered, and so on.

Reported information should be based on a careful review of the actual test article installation and not just the design drawings and specifications. The following are believed to be key parameters for the respective test articles.

4.2.2.2 Longitudinal Barriers

Geometrics. Mounting heights and lengths of rail elements; post spacing; length of test installation; alignment and orientation of barrier relative to vehicular approach; targeted point of impact relative to end of barrier.

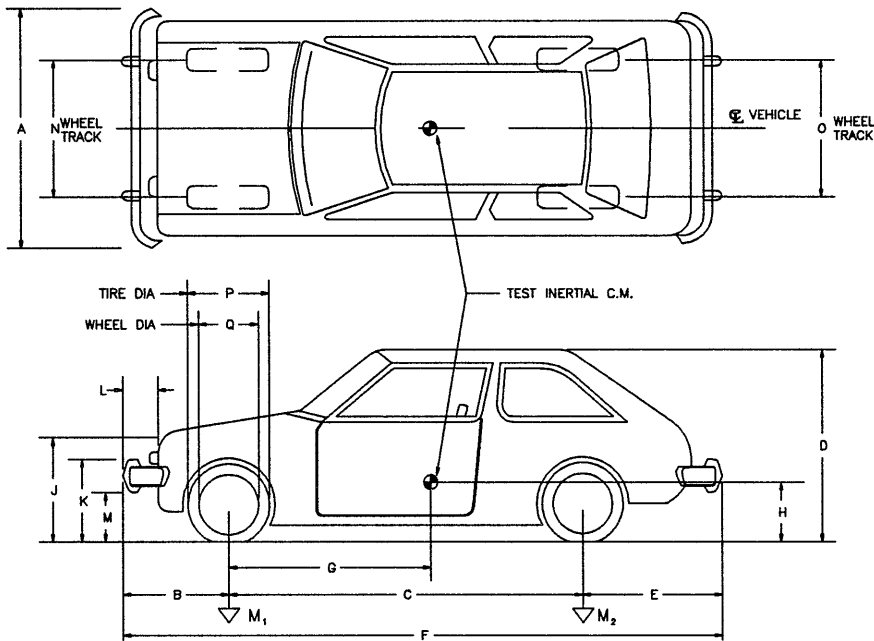
Foundation. Manner in which barrier was supported, including description of structural details of deck and railing-to-deck attachment for bridge railings; details of prototype wing wall or bridge end and its foundation details used in a transition test; embedment procedures for posts embedded in soil (driven, drilled and backfilled, placed in driven inserts, concrete footing, etc.); embedment depth of test article; description of soil and its properties when relevant; description of surface on which free-standing temporary barrier was resting and its frictional properties.

End Conditions. Manner in which the ends of the barrier were anchored, if anchored, including conventional end treatments such as a breakaway cable terminal, or by special end anchorage designs. Some cable barrier systems use a temperature-compensating end anchorage to maintain a specified amount of cable tension. When used, details of these anchorages should be documented including cable tension at the time of the test.

DATE: _____ TEST NO.: _____ VIN NO.: _____ MAKE: _____
 MODEL: _____ YEAR: _____ ODOMETER: _____ TIRE SIZE: _____
 TIRE INFLATION PRESSURE: _____

MASS DISTRIBUTION (kg) LF _____ RF _____ LR _____ RR _____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: _____

ENGINE CID: _____

TRANSMISSION TYPE:

— AUTO

— MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: _____

MASS: _____

SEAT POSITION: _____

GEOMETRY - (cm)

A _____ D _____ G _____ K _____ N _____ Q _____
 B _____ E _____ H _____ L _____ O _____
 C _____ F _____ J _____ M _____ P _____

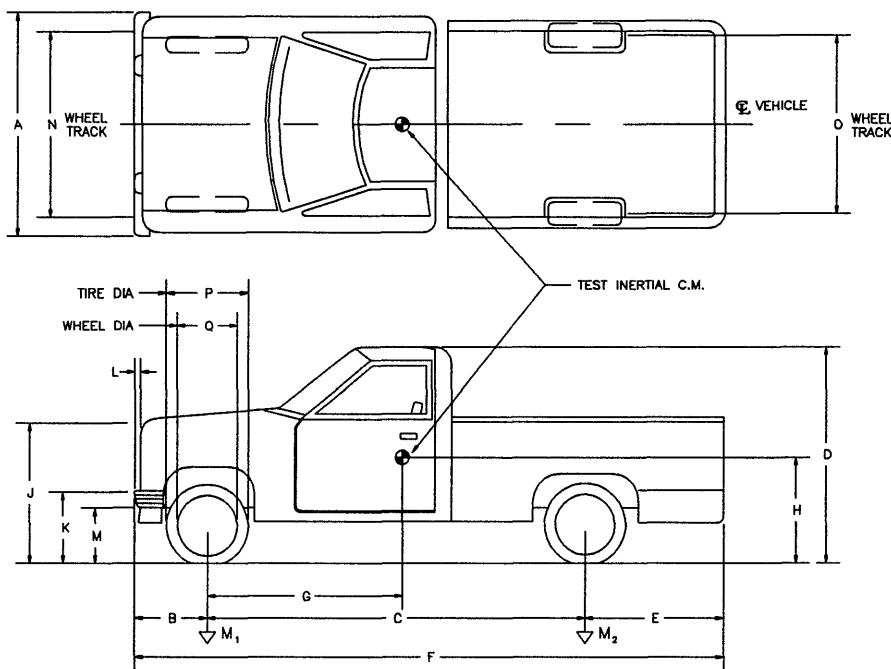
<u>MASS - (kg)</u>	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M ₁	_____	_____	_____
M ₂	_____	_____	_____
M _T	_____	_____	_____

Figure 4.1. 700C and 820C parameters.

DATE: _____ TEST NO.: _____ VIN NO.: _____ MAKE: _____
 MODEL: _____ YEAR: _____ ODOMETER: _____ GVW: _____
 TIRE SIZE: _____ TIRE INFLATION PRESSURE: _____ TREAD TYPE: _____

MASS DISTRIBUTION (kg) LF _____ RF _____ LR _____ RR _____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



ENGINE TYPE: _____

ENGINE CID: _____

TRANSMISSION TYPE:
 — AUTO
 — MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: _____

MASS: _____

SEAT POSITION: _____

GEOMETRY - (cm)

A _____ D _____ G _____ K _____ N _____ Q _____
 B _____ E _____ H _____ L _____ O _____
 C _____ F _____ J _____ M _____ P _____

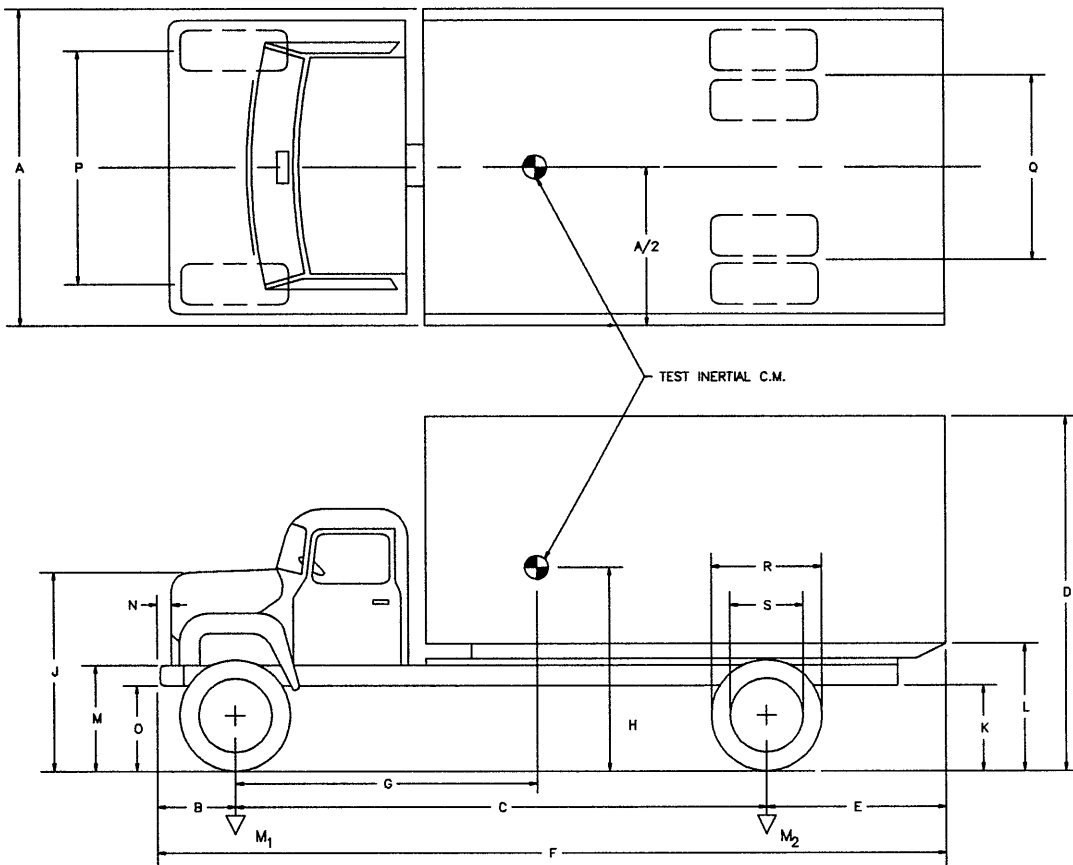
<u>MASS - (kg)</u>	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M ₁	_____	_____	_____
M ₂	_____	_____	_____
M _T	_____	_____	_____

Figure 4.2. 2000P parameters.

DATE: _____ TEST NO.: _____ VIN NO.: _____ MAKE: _____
 MODEL: _____ YEAR: _____ ODOMETER: _____ TIRE SIZE: _____

MASS DISTRIBUTION (kg) LF _____ RF _____ LR _____ RR _____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



GEOMETRY - (cm)

A _____	D _____	G _____	K _____	N _____	Q _____
B _____	E _____	H _____	L _____	O _____	R _____
C _____	F _____	J _____	M _____	P _____	S _____

MASS - (kg)

CURB

TEST INERTIAL

GROSS STATIC

M_1	_____	_____	_____
M_2	_____	_____	_____
M_T	_____	_____	_____

Figure 4.3. 8000S parameters.

DATE: _____ TEST NO.: _____

TRACTOR:

VIN NO.: _____ MAKE: _____ MODEL: _____

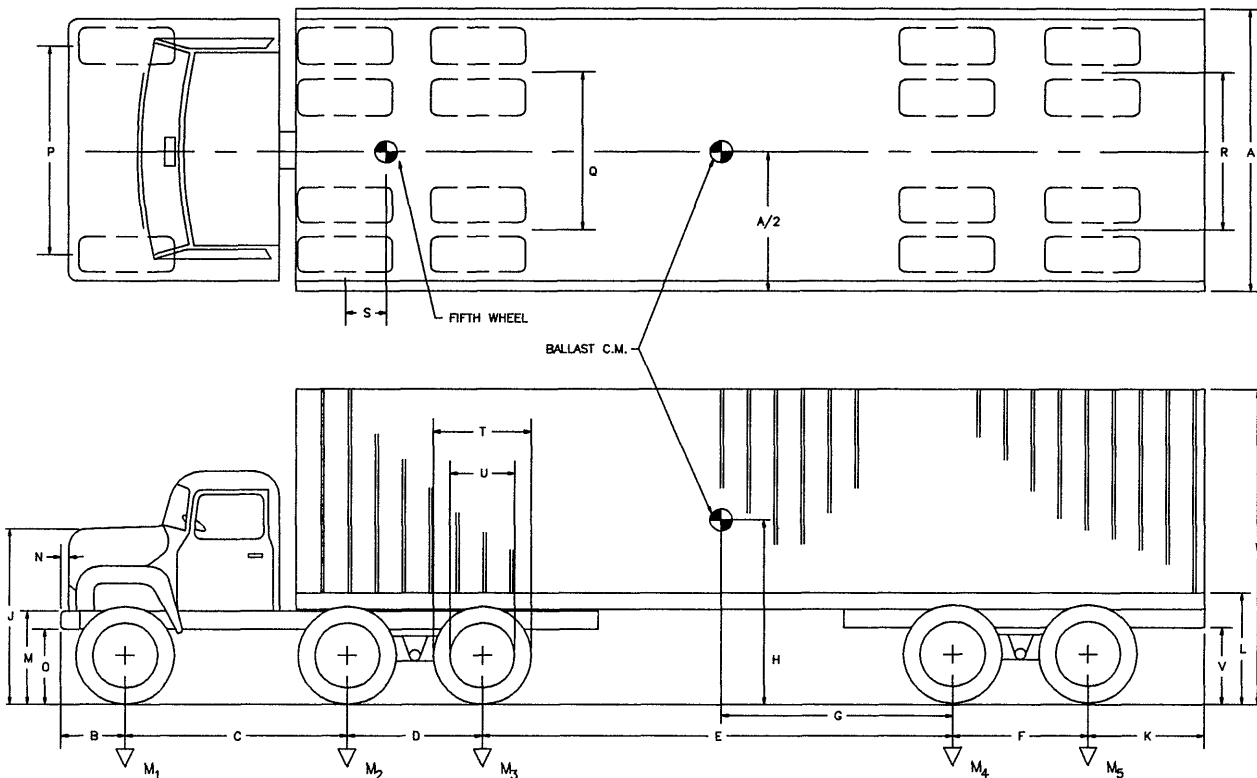
YEAR: _____ ODOMETER: _____

TRAILER:

VIN NO.: _____ MAKE: _____ MODEL: _____

YEAR: _____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:



GEOMETRY - (cm)

A _____	D _____	G _____	K _____	N _____	Q _____	T _____
B _____	E _____	H _____	L _____	O _____	R _____	U _____
C _____	F _____	J _____	M _____	P _____	S _____	V _____
W _____						

MASS - (kg)

	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M ₁	_____	_____	_____
M ₂	_____	_____	_____
M ₃	_____	_____	_____
M ₄	_____	_____	_____
M ₅	_____	_____	_____
M _T	_____	_____	_____

Figure 4.4. 36000V parameters.

DATE: _____ TEST NO.: _____

TRACTOR:
 VIN NO.: _____ MAKE: _____ MODEL: _____

YEAR: _____ ODOMETER: _____

TRAILER:
 VIN NO.: _____ MAKE: _____ MODEL: _____

YEAR: _____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:

GEOMETRY - CM

A _____ D _____ G _____ K _____ N _____ Q _____ T _____
 B _____ E _____ H _____ L _____ O _____ R _____ U _____
 C _____ F _____ J _____ M _____ P _____ S _____ V _____
 W _____

MASS - Kg	CURB	TEST INERTIAL	GROSS STATIC
M ₁	_____	_____	_____
M ₂	_____	_____	_____
M ₃	_____	_____	_____
M ₄	_____	_____	_____
M ₅	_____	_____	_____
M _T	_____	_____	_____

Figure 4.5. 36000T parameters.

Material and Finish Specifications. Specifications for as-tested rail and post material and other major structural elements and for associated hardware (fasteners, nuts, washers, back-up plates, etc.) used in the test article. Actual sizes and physical and chemical properties of hardware items should also be reported.

Connection Details. Connection details of precast concrete barrier elements used in work zones; bolts, nuts, and washers used to anchor a bridge railing post to the deck or abutment; bolts, nuts, and washers and other hardware used to connect rail elements to each other, to supporting posts, or to a bridge abutment; bolt torques when relevant.

4.2.2.3 Terminals and Crash Cushions

Geometrics. Mounting heights of rail elements; post spacing; length of test installation, including back-up structure if used; position of energy absorbing elements; targeted point of impact relative to end of article.

Foundation. Manner in which device was supported, including embedment procedures for posts embedded in soil (driven, drilled and backfilled, placed in driven inserts, concrete footing, etc.); description of soil, and soil properties, when relevant; description of surface on which free-standing device was resting, including its frictional properties when relevant.

End Conditions. Manner in which the ends of the device were anchored, including cable anchors and special back-up structures when used.

Material and Finish Specifications. Specifications for as-tested rail and post material, other structural elements, energy absorbing elements, and associated hardware (fasteners, nuts, washers, backup plates, etc.) used in the test article. Sizes of hardware elements should also be reported.

4.2.2.4 Support Structures, Work Zone Traffic Control Devices, and Breakaway Utility Poles

Geometrics and Mass. Height and width of sign panel; mounting height of sign panel above grade; spacing of multiple-post sign supports; mass of all breakaway support components and utility pole systems; targeted impact point and direction of vehicular approach relative to test article(s); orientation of breakaway mechanism relative to vehicular approach; position of fasteners used in mounting sign panel to wind beams (if used) and in connecting wind beams (or panel) to support posts; dimensions of traffic control devices; mounting height and connection details of lights used on traffic control devices; location of slip planes and hinge points relative to the ground for breakaway supports; height of luminaire pole and luminaire; dimension and orientation of cantilevered luminaire support arm; height of pole and crossarm for utility pole; size and location of all elements mounted on call-box support or mailbox support.

Foundation. Embedment procedures for post or pole embedded in soil (driven, drilled and backfilled, placed in driven inserts, concrete footing, etc.); embedment depth of test article; description of soil and its properties if relevant; description of surface on which free-standing device was resting and its frictional properties if relevant.

Material and Finish Specifications. Specifications for as-tested support structure, sign panel, traffic control device, utility pole, and

associated hardware (fasteners, nuts, washers, back-up plates, etc.) used in the test article; size of hardware elements; physical, chemical and dynamic impact properties if relevant of as-tested devices for which impact performance depends on material fracture or separation, such as certain base bending signs and fragile bases on luminaire poles; results of fatigue and strength tests of key elements.

Connection Details. Bolt torques in slip bases and hinges of breakaway devices, and other connections if relevant.

4.2.2.5 Truck-Mounted Attenuators (TMAs)

Geometrics and Mass. Length, width, and height of attenuator; height of attenuator with respect to the ground; length of supporting truck; mass of TMA and supporting hardware; detailed drawings of mounting hardware; targeted impact point on TMA.

Test Surface. Description of test surface, including type (asphalt or portland cement concrete), finish, and other features that could effect its frictional properties.

Material and Finish Specifications. Specifications for as-tested attenuator, other structural elements, and associated hardware (fasteners, nuts, washers, back-up plates, etc.) used in the test article; sizes of hardware elements.

Supporting Truck. Manner in which the wheels of the supporting truck are braked (i.e., conventional brakes, mechanical lock-up of wheels).

4.3 TEST PARAMETERS

4.3.1 General

Vehicular impact speed and angle, impact point on vehicle and test article, dynamic displacement of the test article, exit speed and angle of the vehicle, vehicular accelerations, and the three-dimensional response of the vehicle are important parameters. Exit speed and angle are measured at the time the vehicle loses contact with the test article. For some support structures such as a yielding sign support, the test article, or parts thereof, may stay in contact with the vehicle for a considerable distance beyond the initial impact point. In those instances, the exit speed and angle may be measured at the time the vehicle clears the foundation or footing supporting the test article. It is also desirable to measure and record the contact length of vehicle with the barrier, airborne distance of vehicle, and maximum rise of vehicle's bumper and wheels. Dynamic strains of the test article may also be of interest in some tests. Key parameters that should be documented during the test phase are given in Table 4.1.

4.3.2 Electronic and Photographic Instrumentation Specifications

Except as noted in this section, it is recommended that SAE J211 OCT88 be used for electronic and optical instrumentation specifications. A copy of this document is included in Appendix C. Note that Part 1 relates to electronic instrumentation and Part 2 relates to photographic instrumentation. Included in Part 1 are specifications on data channel performance requirements, data channel selection, mounting of transducers, sign convention, data

TABLE 4.1. Key test parameters

Parameter	Recommended Measurement Tolerance	Acceptable Measurement Technique	Remarks
Impact/Exit Speed	See Section 4.3.2	(a) Speed Trap (b) High-speed Cine (c) Radar (d) Fifth Wheel	For impact speed only. Minimum film speed of 400 frames/s.
Impact/Exit Angle	± 0.1 deg	(a) High-speed Cine (b) Rate Gyro	Minimum film speed of 200 frames/s. with overhead camera. Integrate rate gyro data to obtain exit angle.
Impact Point Test Article Vehicle	± 30 cm $\pm 0.05 W^*$	Conventional Scales Conventional Scales	
Vehicular Acceleration	See Section 4.3.2 and 4.3.3	Accelerometers	See Sections 4.3.2 and 4.3.3.
Vehicular Trajectory	± 30 cm	High-speed Cine	Minimum film speed of 200 frames/s. Overhead and end views of installation preferred.
Vehicular Roll, Pitch, and Yaw Rates	$\pm 1\%$ of Full Scale	Rate Gyros	Sensitivity should be ≤ 0.02 deg/s/G.
Test Article Dynamic Deformation	± 5 cm	High-speed Cine Displacement Potentiometers	Minimum film speed of 200 frames/sec overhead camera
Occupant (optional) (a) Kinematics	(Not Applicable)	Anthropomorphic or Anthropometric Device and On-board Cine	Onboard movie camera should have minimum film speed of 64 frames/s; camera should be positioned to capture expected dummy motion. As a minimum, the dummy should have gross mass distribution and gross joint movements of a 50th percentile male surrogate.
(b) Kinetics: Accelerations, Forces, and Displacements	See Section 4.3.2	Anthropomorphic Device	50 percentile Hybrid III conforming to Part 572, Subpart E, Title 49 of Code of Federal Regulations, Chapter V (10-1-88 Edition) (Limited to frontal impacts).

* W = width of vehicle.

recording, digital data processing, timing marks, time of initial contact, and presentation of results. With regard to testing of highway safety features, Part 1 of the specifications applies primarily to the determination of impact speed of the test vehicle and to factors related to the measurement, recording, and reduction of vehicular accelerations. Part 1 also applies to factors related to the measurement, recording, and reduction of a surrogate occupant's accelerations, forces, and displacements. To the extent that photographic instrumentation is used for these same purposes, Part 2 of the specifications is applicable.

With regard to SAE J211 OCT88, the following exceptions and additions are made:

- Contrary to the apparent recommendation in Part 1, Section 5, it is not necessary that all data be gathered at class 1000 or higher. Rather it is recommended that the frequency response classes given in Table 1 of Part 1, Section 5, be used. Specifically, note that data for "vehicle structural accelerations for use in integration for velocity or displacement" should be gathered at channel class 180.
- With regard to Part 1, Section 12, it is recommended that vehicular accelerations be filtered at a "channel frequency class" of 60 Hz prior to plotting acceleration versus time data presented in the test report.
- Section A2.2 is optional and Section A.3 is not applicable.
- Part 2, Section 3.1.1, is not applicable if a wide-angle lens is used because most such lenses cannot meet "distortion index."

With regard to the measurement of accelerations, it will be noted that SAE J211 OCT88 does not specify a Channel Amplitude Class (CAC), that is, the maximum acceleration level for the accelerometer. Selection of the CAC must be made by the testing agency. However, the CAC should be selected so as to maximize the accuracy of the expected results without exposing the accelerometer to undue risk of damage. In general, good accuracy can be expected if measured accelerations are near the midrange of the accelerometer limits. To the extent possible the CAC should be selected based on a review of results from similar tests and the best judgment of the testing agency.

It should also be noted that the sign convention in SAE J211 OCT88 differs from that in *NCHRP Report 230*. The recommended convention, in accordance with SAE J211 OCT88, for a vehicle is as follows:

- x-Positive in the normal forward motion direction,
- y-Positive toward the right, and
- z-Positive vertically downward.

The origin of these axes is typically placed at the center of mass of the vehicle. The positive axes are shown in Figure 4.6.

4.3.3 Accelerometer Placement and Data Reduction for Test Vehicles 700C, 820C, and 2000P

It is important that vehicular accelerations be measured or calculated with respect to a common point so that meaningful and consistent results can be expected from various testing agencies. Vehicular accelerations at the center of mass of the vehicle are used in the computation of one of the critical evaluation criteria,

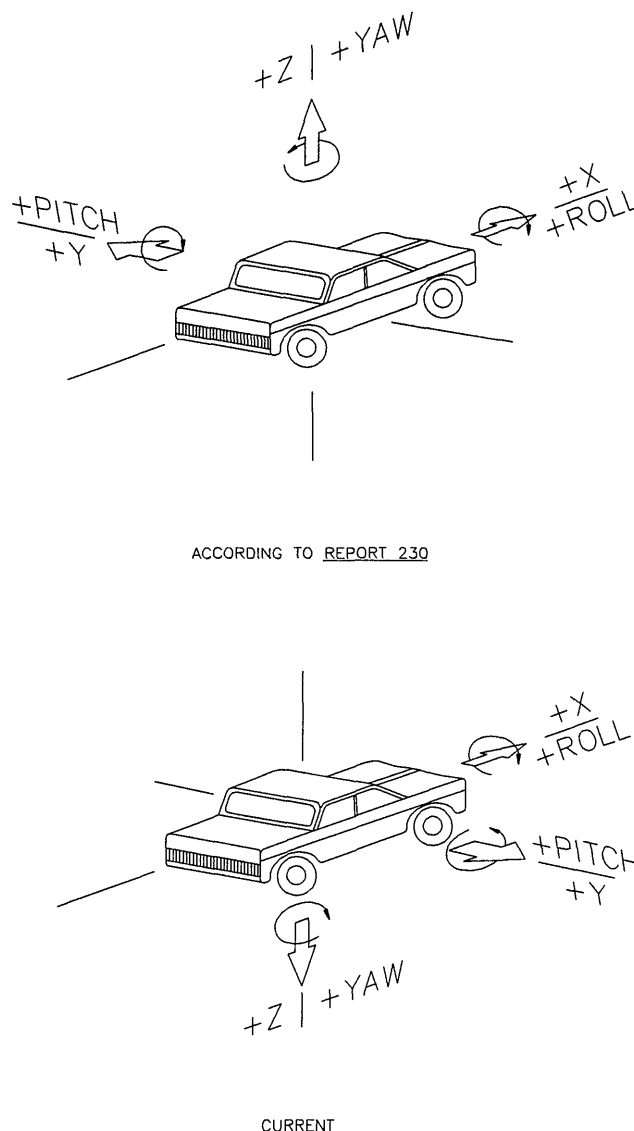


Figure 4.6. Positive vehicular sign convention.

that is, occupant risk. It is therefore important that a tri-axial set of accelerometers be placed at or very near the vehicle's center of mass. If the accelerometers cannot be placed within a ± 5 cm radial, measured in the x - y plane, of the center of mass, it is recommended the instrumentation and data reduction method given in Appendix A, Section A4.3.3, be used.

Accelerometers should be mounted on a major structural element of the vehicle so that "rigid" vehicular body motions are measured. A metal block is recommended for combining accelerometers on a common structure; the block can then be attached to the vehicle. The mass of the block should be minimal so as not to appreciably alter the frequency response of the structural element to which it is attached.

Although occupant risk evaluation using the flail space model is not required for the 8000S, 36000V, and 36000T vehicles, it is recommended that a procedure similar to that in Section A4.3.3 be used to measure accelerations in the subject vehicles. Note that for the 8000S vehicle two sets of longitudinal and lateral

TABLE 4.2. Key post-test parameters

Parameter	Suggested Measurement Tolerance	Acceptable Measurement Technique	Remarks
<u>Test Article</u> Permanent Deformation or Displacement (if applicable) Final Rest Position (if applicable) General Damage	± 5 cm ± 30 cm (Not Applicable)	Conventional Scales Transit Conventional Scales Transit Visual Inspection	See discussion in Section 5.2. Locate and report significant debris. See discussion in Section 5.3. Identify and report significant damage.
<u>Test Vehicle</u> Final Rest Position Exterior Damage Interior Damage Undercarriage Damage	± 30 cm ± 5.0 deg (Not Applicable) (Not Applicable) (Not Applicable)	Conventional Scales Transit Visual Inspection and Photos Visual Inspection and Photos See Appendix E Visual Inspection and Photos	VDS standard photos should be shown in report. See discussion in Section 4.4. See discussion in Section 4.4.

accelerometers are needed forward of the cab/cargo van interface to determine accelerations at any point along the x-axis forward of the interface, and two sets are needed aft of the interface to determine accelerations at any point aft of the interface. Also, two sets are needed in the tractor and two sets are needed in the trailer to determine accelerations at any point along the x-axis in the tractor and trailer of vehicles 36000V and 36000T.

4.4 POST-TEST PARAMETERS

After the test, deformation, damage and final rest position of both the test article (or portions thereof) and the vehicle should be documented and reported. This includes the roll-ahead distance for the support truck in a TMA test. Both the "vehicle damage scale" (VDS)(75) and "collision damage classification" (CDC) (76) should be determined and reported. Key parameters that should be documented in the post-test phase are given in Table 4.2. In addition to the recommended measurements, it is important that these parameters be fully documented photographically.

Collapse and failure modes of the test article and components thereof should be described to the extent possible. This includes the foundation when applicable, fasteners, and other hardware items. Follow-up material testing to determine physical and chemical properties is recommended for an unexpected component failure. Results of the follow-up tests should be discussed and presented in the test report.

One of the factors considered in the evaluation of a crash test is the structural integrity of the occupant compartment (see Chapter 5). These criteria require that the test article not penetrate the occupant compartment and that there be no deformations of or intrusions into the occupant compartment that could cause a

disabling injury. In the absence of an acceptable measure of such deformations or intrusions, it is essential that adequate documentation in the form of photographs of occupant compartment damage be made and reported. Photographs of the interior prior to the test should also be made to permit direct comparisons of before and after conditions. Until an acceptable methodology is developed, it is recommended that the procedure given in Appendix E be used to compute and document an Occupant Compartment Deformation Index (OCDI). Although it is recommended that the OCDI be used for information purposes only and that it not be used to determine acceptance of a test, its use will permit some degree of quantification of occupant compartment damage. As experience is gained with its use, definitive acceptance criteria may be established in the future. Note that the OCDI will also be used by the European Committee for Standardization to quantify occupant compartment deformation (77).

Occasionally the undercarriage of the vehicle will make contact with the test article. Damage to the oil pan, gas tank, or other components may occur. Such instances should be documented and reported.

4.5 ADDITIONAL PARAMETERS

Recommendations given in the foregoing sections relative to data acquisition are based on tests to date of known test articles. As new safety features are developed with special design and performance characteristics, there may be a need to amend these recommendations. These recommendations should therefore not be considered all-inclusive. Other parameters peculiar to a test article or to its expected application or parameters peculiar to the test vehicle may require additional data acquisition techniques.

CHAPTER 5

EVALUATION CRITERIA

5.1 GENERAL

Recommended safety performance evaluation criteria for safety features are given in Table 5.1. Three dynamic performance evaluation factors are given together with recommended evaluation criteria and applicable tests. The factors are (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicular response.

To the extent possible and practicable, limiting values recommended for the respective evaluation criteria are based on current technology and, when necessary, on the collective judgment of experts in roadside safety design. Establishment of performance criteria has been based on a "state-of-the-possible" philosophy since the late 1960s. That philosophy basically contends that as technological and economic conditions permit, higher levels of safety performance should be expected of certain safety features than others. Thus, impact performance requirements of a breakaway sign or luminaire support are more demanding than a crash cushion. Recommended values were also made in consideration of the limitations of the recommended test procedures and methodologies used to estimate occupant risk. As a consequence and in view of the very complex nature of vehicular collisions, the complex manner in which an occupant responds dynamically to the collision, and the complex nature of human tolerances to impact, the recommended criteria should be treated as general guidelines and not as absolute criteria. The adequacy of these or other criteria must ultimately be established by the agency responsible for the implementation of the safety device being evaluated.

Note that the evaluation criteria relate to the impact performance of the safety feature. Costs (i.e., installation, maintenance, damage repair, etc.), aesthetics, maintainability, durability, and other service requirements are not evaluated.

5.2 STRUCTURAL ADEQUACY

Structural adequacy is generally the first factor to be evaluated, and the safety feature should perform successfully according to the requirements presented in Table 5.1. Depending on its intended function, the feature may satisfy structural adequacy by redirecting the vehicle, by stopping the vehicle in a controlled manner, or by permitting the vehicle to break through the device.

It should be noted that structural adequacy criteria refer to the structural requirements associated with the impact itself. The criteria do not imply, for example, that a sign support system that meets the structural adequacy requirements of a test will meet the structural adequacy requirements of wind and ice loads or other environmental considerations when applicable.

Wide use is now made of temporary longitudinal barriers in work zones. Free-standing, unanchored precast concrete barriers are most commonly used. Increasing use is being made of a "moveable," precast concrete barrier in work zones to separate traffic in high-occupancy vehicle lanes. When used for the latter, the moveable barrier is typically moved laterally from one lane to another, one or more times per day. A primary concern for barriers of this type is the deflection they undergo during a vehicular impact. Because the amount a given installation can deflect without adverse consequences depends on site conditions, it is not feasible to establish limiting deflection values for crash tests of these barriers. Rather, it is important to accurately measure and report barrier displacement that occurs during the test so that a user agency can make an objective assessment of the appropriateness of the barrier for its intended application.

5.3 OCCUPANT RISK

Risk of occupant injury during impact with a highway safety feature depends to a large extent on the crashworthiness of the impacting vehicle. Crashworthiness depends in large part on the design of the occupant compartment including factors such as structural integrity, padding, restraint system, and so on. However, to the extent possible, the variability of vehicular crashworthiness has been removed from safety feature evaluation. Occupant risk is appraised according to gross vehicular accelerations because they are primarily functions of the safety feature design and the external structural design of the test vehicle. Whereas the highway engineer is ultimately concerned with safety of the vehicle's occupants, the occupant risk criteria of Table 5.1 should be considered as guidelines for generally acceptable dynamic performance.

Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians, or workers in a construction zone if applicable. The degree to which detached elements, fragments, or other debris and the degree to which the displacement of a temporary barrier presents a hazard to other traffic, pedestrians, and workers in a construction zone will depend on the location of the feature and the impact conditions. A sign in a median when struck by a vehicle may pose a hazard if detached elements encroach into opposing traffic lanes. The same sign when struck on the roadside may be of little concern except to occupants of the impacting vehicle. Fragments and debris from an impact with a traffic control device in a construction zone may or may not pose a hazard to workers in the zone, depending on their location relative to the device and the impact conditions. Consequently, it is not

practical to establish absolute limits on test article trajectory, debris scatter, or barrier displacement. Rather, it is important to accurately record and report test article trajectory and debris scatter so that a user agency can make an objective assessment of the appropriateness of the safety feature for the intended application.

A factor listed in item D concerns deformations and intrusions into the occupant compartment. Of necessity, this factor must be assessed in large part by the judgment of the test agency and the user agency, or both. Risk of injury from a deformation depends on location, extent, and rate of deformation. In the absence of a widely accepted measure of risks associated with deformations or intrusions, it is essential that adequate documentation in the form of photographs and measurements of occupant compartment damage be made and reported. Photographs of the interior prior to the test should also be made to permit direct comparisons of before and after conditions. Until an acceptable methodology is developed, the procedure given in Appendix E may be used to compute and document an Occupant Compartment Deformation Index (OCDI). Although the OCDI should be used for information purposes only and should not be used to determine acceptance of a test, its use will permit some degree of quantification of occupant compartment damage. As experience is gained with its use, definitive acceptance criteria may be established in the future.

Although not a specific factor in assessing test results, integrity of the test vehicle's fuel tank is of concern. It is preferable that the fuel tank remain intact and unpunctured. Damage to or rupture of the fuel tank, oil pan, floor pan, or other features that might serve as a surrogate of a fuel tank should be reported.

For the majority of tests, a key requirement for occupant risk evaluation is for the impacting vehicle to remain upright during and after the collision, although moderate rolling, pitching, and yawing are acceptable. This requirement has the effect of minimizing the vertical component of vehicular acceleration; thus, this component is not normally evaluated in a typical crash test. Although it is preferable that all vehicles remain upright, this

requirement is not applicable to tests involving the 8000S, 36000V, and 36000T vehicles, and all tests within test level 1 for terminals and crash cushions. See Appendix A, Section A3.2.2, for a discussion of these exceptions.

Occupant risk is also assessed by the response of a hypothetical, unrestrained front seat occupant whose motion relative to the occupant compartment is dependent on vehicular accelerations. The "point mass" occupant is assumed to move through space until striking a hypothetical instrument panel, windshield, or side structure and subsequently is assumed to experience the remainder of the vehicular acceleration pulse by remaining in contact with the interior surface. The two performance factors are (1) the lateral and longitudinal component of occupant velocity at impact with the interior surface and (2) the highest lateral and longitudinal component of resultant vehicular acceleration averaged over any 10-ms interval for the collision pulse subsequent to occupant impact. Performance factor two is referred to as the ridedown acceleration. Methods for calculating the impact velocity and ridedown acceleration components are given in Appendix A, Section A5.3. Generally, low values for these factors indicate less hazardous safety features. While a surrogate occupant is required in tests with the 820C and 700C vehicles and is optional in other tests, its dynamic and kinematic responses are not required or used in occupant risk assessment; hypothetical occupant compartment impact velocity and ridedown accelerations are calculated from vehicular accelerations.

It is also necessary to assess risk of injury to the driver of a supporting truck in a TMA system. Because the types of impacts in this case are primarily unidirectional and the supporting truck is accelerated forward, the driver will not move forward, at least initially, and is restrained from flailing rearward by the seat and headrest, which should be standard on these vehicles. As such, the primary risk of injury would stem from ridedown accelerations as the vehicle is accelerated forward. It is therefore recommended that ridedown acceleration criteria be used as the primary assessment of the risk of injury to the driver of a supporting truck in a TMA system.

TABLE 5.1. Safety evaluation guidelines

Evaluation Factors	Evaluation Criteria	Applicable Tests ^a
Structural Adequacy	A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38
	B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	60, 61, 70, 71, 80, 81
	C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.	30, 31, 32, 33, 34, 39, 40, 41, 42, 43, 44, 50, 51, 52, 53

^a Test numbers refer to last two digits in Test Designation for each Test Level unless otherwise noted.

TABLE 5.1. (Continued)

Evaluation Factors	Evaluation Criteria	Applicable Tests ^a	
Occupant Risk	D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted. See discussion in Section 5.3 and Appendix E.	All	
	E. Detached elements, fragments or other debris from the test article, or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.	70, 71	
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	All except those listed in Criterion G.	
	G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	12, 22, 30 ^b , 31 ^b , 32 ^b , 33 ^b , 34 ^b , 35 ^b , 36 ^b , 37 ^b , 38 ^b , 39 ^b , 40 ^b , 41 ^b , 42 ^b , 43 ^b , 44 ^b	
	H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:		
	Occupant Impact Velocity Limits (m/s)		
	Component		Preferred Maximum
	Longitudinal and Lateral		9 12
	Longitudinal	3 5	60, 61, 70, 71
	I. Occupant ridedown accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:		
Occupant Ridedown Acceleration Limits (G's)			
Component	Preferred Maximum		
Longitudinal and Lateral	15 20		10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81
J. (Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulation, Chapter V (10-1-88 Edition). See Section 5.3 for limitations of Hybrid III dummy.	10, 20, 30, 31, 32, 33, 34, 36, 40, 41, 42, 43, 50, 51, 52, 53, 60, 61, 70, 71, 80, 81		

^a Test numbers refer to last two digits in Test Designation for each Test Level unless otherwise noted.^b For Test Level 1 only.

TABLE 5.1. (Continued)

Evaluation Factors	Evaluation Criteria	Applicable Tests ^a
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	All
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction (see Appendix A, Section A5.3 for calculation procedure) should not exceed 20 G's.	11, 21, 35, 37, 38, 39
	M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	10, 11, 12, 20, 21, 22, 35, 36, 37, 38, 39
	N. Vehicle trajectory behind the test article is acceptable.	30, 31, 32, 33, 34, 39, 42, 43, 44, 60, 61, 70, 71, 80, 81

^a Test numbers refer to last two digits in Test Designation for each Test Level unless otherwise noted.

Recommended limits for occupant impact velocity and ridedown acceleration are given in Table 5.1. Note that two values are given for each parameter, a "preferred" limit and a "maximum" limit. As implied, it is desirable that the occupant risk indices not exceed the preferred values, and it is recommended that they not exceed the maximum values. Reference should be made to Appendix A, Section A5.3, for the rationale used in selecting these values. Establishment of absolute occupant risk limits is a policy decision and accordingly must be made by the user agency responsible for the implementation of the recommendations contained herein.

As indicated in Table 5.1, if a dummy is to be used to supplement the assessment of occupant risk, it is recommended the Hybrid III dummy be used. However, note that the Hybrid III dummy is valid for *frontal or head-on impacts* only, that is, those in which dummy movement is essentially parallel to the longitudinal vehicular axis (x-axis, as shown in Figure 4.6). Specifications, calibration, and instrumentation of the Hybrid III dummy should be in accordance with Part 572, Subpart E, Title 49 of the *Code of Federal Regulations*, Chapter V (10-1-88 Edition). Response data should conform to Part 571.208, Title 49 of the CFR, Chapter V (10-1-88 Edition). There is no dummy capable of accurately simulating the kinetics and kinematics of an occupant for oblique movements, that is, those in which occupant movement has both x and y components. Oblique occupant movement typically occurs when the vehicle is redirected away from the feature being impacted, such as a longitudinal barrier.

Although not required, testing agencies are encouraged to calculate and report the Theoretical Head Impact Velocity (THIV), the Post-Impact Head Deceleration (PHD), and the Acceleration Severity Index (ASI), as described in Appendix F. The

THIV, PHD, and the ASI have been adopted by the European Committee for Standardization (CEN) (77) as measures of occupant risks. At some time in the future, it is expected that the U.S. and CEN will develop common impact performance standards for highway features. By calculating and reporting the THIV, PHD, and the ASI, a database will be developed from which comparisons can be made relative to the flail space model and from which decisions can be made as to appropriate measures of occupant risk.

5.4 POST-IMPACT VEHICULAR TRAJECTORY

Vehicular trajectory hazard is a measure of the potential of the post-impact trajectory of the vehicle to cause a subsequent multivehicle accident, thereby subjecting occupants of other vehicles to undue hazard or to subject the occupants of the impacting vehicle to secondary collisions with other fixed objects. As indicated in Table 5.1, it is preferable that the vehicle trajectory and final stopping position intrude a minimum distance, if at all, into adjacent or opposing traffic lanes. Criterion "L" is included to limit pocketing or snagging of the vehicle and the post-impact consequences of excessive pocketing or snagging, such as a high vehicular exit angle or spin-out of the vehicle. It is preferable that the vehicle be smoothly redirected (for redirective devices), and this is typically indicated when the exit angle is less than 60 percent of the impact angle. Acceptable post-impact behavior may also be achieved if the vehicle is decelerated to a stop while vehicular-barrier contact is maintained, provided all other relevant criteria of Table 5.1 are satisfied. Note that if the barrier is within a lane width of adjacent traffic, the slowed or stopped vehicle may pose risks to oncoming motorists. As

indicated for certain classes of safety features, vehicular trajectory behind the test article is acceptable.

5.5 GEOMETRIC FEATURES

Tests of a geometric feature, such as a ditch, driveway, embankment, or curb, typically involve three-dimensional vehicular motions. Also, the duration of the test is usually long (up to 5 s or more) in comparison to a test of a barrier or other highway safety feature (typically 0.30 s or less). As a consequence, an unrestrained occupant can be expected to flail about the occupant compartment in three dimensions over an extended time duration, possibly contacting a given surface(s) more than once. For these reasons, the flail space model is generally not applicable.

Fortunately, in tests of most geometric features there are no design elements that would cause sudden and large vehicular velocity changes. The primary concern is overturn of the vehicle as it traverses the feature.

In the absence of more objective criteria, the following procedures and evaluation criteria may be used for a geometric feature:

- (a) Part F of Table 5.1 must be satisfied.
- (b) Compute average accelerations in the longitudinal and lateral directions for each consecutive 50-ms period for the duration of the event.
- (c) If the average longitudinal or lateral acceleration computed in step b exceeds 2 Gs during any 50-ms period, apply the flail space model at the beginning of the period over which the average acceleration was computed. Evaluate the results of the flail space model according to Parts H and I of Table 5.1.

CHAPTER 6

TEST DOCUMENTATION

6.1 GENERAL REPORTING RECOMMENDATIONS

Of primary importance in the guidelines presented herein is the preparation of a comprehensive test report. The test(s) should be documented in sufficient detail so that, if necessary, others could repeat the test(s) and obtain similar results. Liberal use of photographs is encouraged to document before, during, and after test conditions. Reference should be made to Chapter 4 for key pretest, test, and post-test parameters.

A recommended table of contents for the test report is given in Figure 6.1. In general, the report should include at a minimum the following information:

Identification. The test report should include the name of personnel responsible for the test(s), the name and address of the testing organization, location of test facility, and the date of the test(s).

Test Vehicle. A description of the test vehicle should be given in the report. Data described in Sections 4.2.1 and 4.3.3 should be included.

Test Article. The test article should be fully described with engineering drawings and material specification. Key parameters that should be recorded are given in Section 4.2.2. It is preferable that engineering drawings be made with a computerized drafting system to facilitate their use by others. As appropriate, revisions to the design made during the course of the test program should be fully documented. Of particular importance is the delineation of special fabrication and installation procedures (such as heat treatment, weldments, bolt tension, galvanizing in critical stressed areas, etc.) that may influence impact performance.

Test Soil. If relevant, the type of soil used, why it was selected, its adherence to recommended specifications, and its properties at the time of the test should be reported.

Test Procedures. Key test procedures are given in Section 4.3 and Table 4.1. A description of the test facility and associated equipment should be contained in the report. It is desirable that weather conditions that may affect test results be reported, including those at the time of the test as well as those preceding the test (e.g., prolonged duration of subfreezing weather or prolonged duration of rainy weather). The data acquisition systems should be fully described, together with the procedures used in calibrating and processing the data.

Findings. To facilitate comparison of findings from two or more testing agencies, a findings presentation format, as described in Table 6.1, is recommended. It is also recommended that the report contain a summary page with the information given in Figure 6.2. A brief description of the items in Figure 6.2 follows:

1. Sequential photos may be taken from selected frames of high-speed film or video, or from frames of a sequence camera.

I.	INTRODUCTION
A.	Problem
B.	Background/Literature Search
C.	Objectives/Scope of Research
II.	TECHNICAL DISCUSSION
A.	Test Parameters
1.	Test Facility
2.	Test Article--Design and Construction
3.	Test Vehicles
4.	Soil Conditions
B.	Test Conditions and Results
1.	Impact Description/Vehicle Behavior
2.	Barrier Damage/Debris Patterns
3.	Vehicle Damage
4.	Dummy Behavior (optional)
C.	Assessment of Test Results
1.	Occupant Risk
2.	Structural Adequacy
3.	Vehicle Trajectory Hazard
III.	CONCLUSIONS AND RECOMMENDATIONS
	APPENDIX:
A.	Test Vehicle Equipment and Guidance Methods (Details)
B.	Photo Instrumentation (Diagrams, specifications, details and analysis)
C.	Electronic Instrumentation (Diagrams, specifications, details, and analysis)
D.	Detailed Drawings of Test Article
E.	Material Sample Test Results
F.	Test Article Construction Experience and/or Installation Procedures (if unusual)
G.	References

Figure 6.1. Recommended table of contents for crash test report.

They should begin at impact and should show the response of the vehicle/test article during the contact phase. For longitudinal barrier tests, an overhead view and/or a view parallel to the barrier is preferred. For terminal or crash cushion tests, an overhead view is preferred. For other features, a view perpendicular to the vehicle's approach path is preferred.

2. The plan view of the installation should show the overall layout of the installation, the impact point of the vehicle with the test article, and the post-impact trajectory of the vehicle and the test article.

3. An elevation view of the test article should show basic dimensions, heights, and if applicable the depth of embedment of the test article.

4. The test agency, test number, and date of the test should be given here.

TABLE 6.1. Recommended format for reporting of findings

Item	Description	Format
Photography Still	Before and after test of vehicle and test article	Photographs
High-Speed Cine	Selected sequential frames (8 minimum) during impact	Photographs
Accelerations Vehicle	x,y,z components; filtered (see Section 4.3.2)	Plots ^b
Dummy ^a	x,y,z components of head and chest (see Section 4.3.2)	Plots ^b
Angular Displacements	Roll, pitch, and yaw vehicular displacements	Plots ^b
Force ^a Seat Belt Dummy Femur	Seat belt load cell Femur load cell	Plots ^b Plots ^b
Test Article Deformation Permanent Dynamic	Profile of deformation Maximum deformation	Plot ^b /Table Text
Damage Test Article Vehicle	Damage to key elements Damage to exterior and interior	Photos and Narrative Photos and Narrative VDS Scale CDC Scale OCDI Scale

^a Optional.

^b Plots should be scaled to maximize resolution of parameters.

5. To the extent possible and as space permits, the test article should be described here. *Type*-Give basic type of article tested (e.g., longitudinal barrier/bridge rail). *Installation length*-For a longitudinal barrier test, this is the length of the standard barrier section, exclusive of the end terminals. For a terminal test, it is the length of the terminal and the adjoining longitudinal barrier; lengths of each should be given separately. For a crash cushion test, it is the length of the cushion and backup structure, if necessary; lengths of each should be given separately. For a TMA, it is the length of the cushion and the support truck; lengths of each should be given separately. It is not applicable for tests of support structures, work zone traffic control devices, and breakaway utility poles. *Size, dimensions, and material of key elements*-Sizes and dimensions and material for key elements of the test article, such as rails, posts, support structures, traffic control devices, and utility poles, should be given.

6. If applicable, reference should be made to the type of soil used (e.g., "standard soil of Section 2.2.1.1"), and a note should be made if soil conditions differed from those recommended therein.

7. Test vehicle parameters of interest are: *Type*-Indicate whether a production model vehicle or a surrogate (bogie or pendulum) test vehicle was used. *Designation*-Indicate which

of the six test vehicles was used in the test (i.e., 700C, 820C, 2000P, 8000S, 36000V, or 36000T). *Model*-Indicate actual make and model year if a production model vehicle was used or the make and model year simulated by the surrogate. *Mass*-See Section 2.4.2.1 for definition of these parameters.

8. Terms are self-explanatory.

9. The exit conditions should be measured at the time the vehicle loses contact with the test article. See Section 4.3.1 for further discussion of exit conditions.

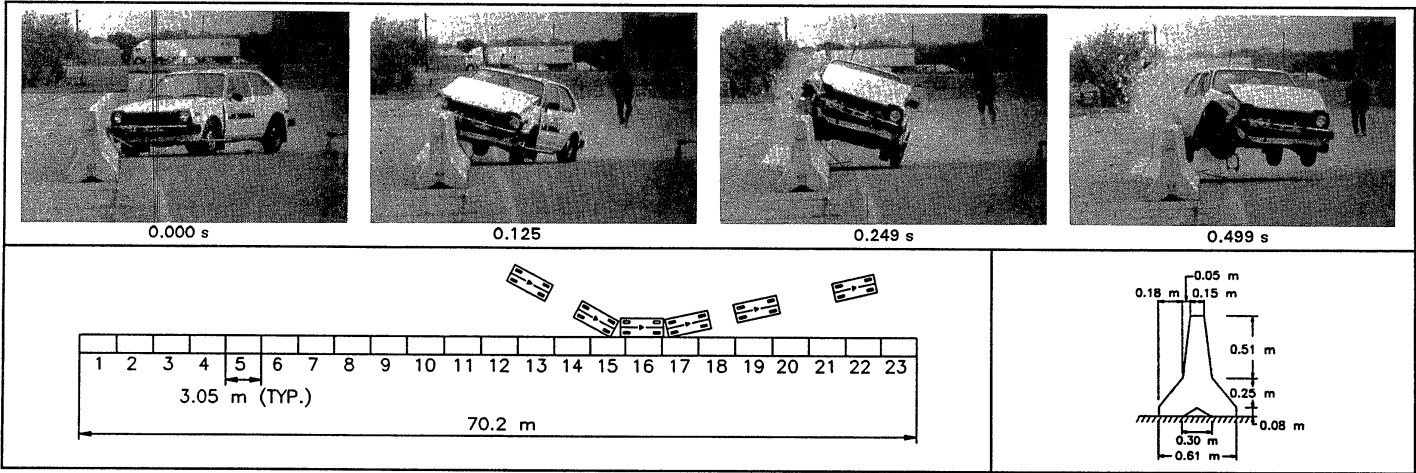
10. Occupant risk values are computed as described in Section A5.3 of Appendix A, and in Appendix F.

11. Dynamic deflection of a test article is the maximum deflection that occurs during the impact. Permanent deflection is the residual deflection remaining after the impact. These measurements normally apply to longitudinal barriers, terminals, crash cushions and TMAs.

12. See Section 4.4 for discussion of VDS and CDC. See Section 4.4 and Appendix E for discussion of OCDI.

13. Indicate the maximum roll, pitch, and yaw angles of the vehicle during the test. See Figure 4.6 for definition and sign convention of these angles.

Shown in Figure 6.3 is an example of the use of Figure 6.2.



4. General Information

Test Agency
 Test No.
 Date

5. Test Article

Type
 Installation Length (m)
 Size and/or dimension and material
 of key elements

6. Soil Type and Condition

7. Test Vehicle

Type
 Designation
 Model
 Mass (kg) Curb
 Test Inertial
 Dummy(s)
 Gross Static

8. Impact Conditions

Speed (km/h)
 Angle (deg)

9. Exit Conditions

Speed (km/h)
 Angle (deg)

10. Occupant Risk Values

Impact Velocity (m/s)
 x-direction
 y-direction
 THIV (optional)
 Ridedown Acceleration (g's)
 x-direction
 y-direction
 PHD (optional)
 ASI (optional)

11. Test Article Deflections (m)

Dynamic
 Permanent

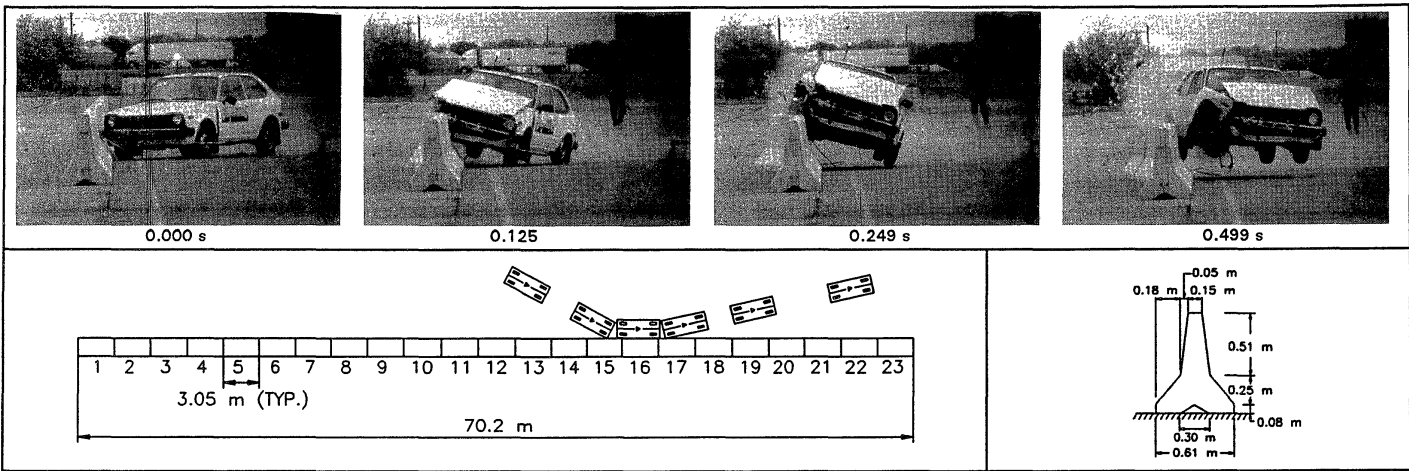
12. Vehicle Damage

Exterior
 VDS
 CDC
 Interior
 ODCI

13. Post-Impact Vehicular Behavior

Maximum Roll Angle (deg)
 Maximum Pitch Angle (deg)
 Maximum Yaw Angle (deg)

Figure 6.2. Recommended summary sheet for crash test results.



General Information

Test Agency	.....	<u>Texas Transportation Institute</u>
Test No.	.....	<u>7110-1</u>
Date	.....	<u>03/22/90</u>
Test Article		
Type	.....	<u>Longitudinal Barrier/ Temporary Barrier</u>
Installation Length (m)	.....	<u>70.2</u>
Size and/or dimension and material of key elements	.....	<u>3.05 m Precast Concrete Sections</u>
Soil Type and Condition	.....	<u>N/A</u>
Test Vehicle		
Type	.....	<u>Production Model</u>
Designation	.....	<u>820 C</u>
Model	.....	<u>1981 Honda Civic</u>
Mass (kg)		
Curb	.....	<u>830</u>
Test Inertial	.....	<u>817</u>
Dummy(s)	.....	<u>77</u>
Gross Static	.....	<u>894</u>
Impact Conditions		
Speed (km/h)	.....	<u>71.8</u>
Angle (deg)	.....	<u>28.0</u>
Exit Conditions		
Speed (km/h)	.....	<u>36.2</u>
Angle (deg)	.....	<u>12.5</u>

Occupant Risk Values

Impact Velocity (m/s)		
x-direction	.....	<u>6.2</u>
y-direction	.....	<u>4.9</u>
THIV (optional)	.....	<u>7.3</u>
Ridedown Acceleration (g's)		
x-direction	.....	<u>-3.7</u>
y-direction	.....	<u>-8.2</u>
PHD (optional)	.....	<u>8.4</u>
ASI (optional)	.....	<u>0.8</u>
Test Article Deflections (m)		
Dynamic	.....	<u>0.43</u>
Permanent	.....	<u>0.43</u>
Vehicle Damage		
Exterior		
VDS	.....	<u>02FR4</u>
CDC	.....	<u>02FREW3</u>
Interior		
OCDI	.....	<u>RS0000011</u>
Post-Impact Vehicular Behavior		
Maximum Roll Angle (deg)	.....	<u>19</u>
Maximum Pitch Angle (deg)	.....	<u>11</u>
Maximum Yaw Angle (deg)	.....	<u>35</u>

Figure 6.3. Example of recommended summary sheet for crash test results.

TABLE 6.2. Example of recommended assessment summary page

Test No. 7110-1
 Date 03/20/90
 Test Agency Texas Transportation Institute

Evaluation Criteria	Test Results	Assessment									
<p>Structural Adequacy</p> <p>A. Test article shall contain and redirect the vehicle; the vehicle shall not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable.</p>	<p>Vehicle contained and smoothly redirected.</p>	<p>Pass</p>									
<p>Occupant Risk</p> <p>H. Occupant impact velocities (see Appendix A5.3 for calculation procedure) shall satisfy the following:</p> <table border="1" data-bbox="193 768 810 936"> <thead> <tr> <th colspan="3">Occupant Impact Velocity (m/s)</th> </tr> <tr> <th>Component</th> <th>Preferred</th> <th>Maximum</th> </tr> </thead> <tbody> <tr> <td>Longitudinal and Lateral</td> <td>9</td> <td>12</td> </tr> </tbody> </table>	Occupant Impact Velocity (m/s)			Component	Preferred	Maximum	Longitudinal and Lateral	9	12	<p>Longitudinal Impact Vel. = 7 m/s Lateral Impact Vel. = 10 m/s</p>	<p>Pass Marginal</p>
Occupant Impact Velocity (m/s)											
Component	Preferred	Maximum									
Longitudinal and Lateral	9	12									
<p>Vehicle Trajectory</p> <p>M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.</p>	<p>Exit angle less than 60% of impact angle.</p>	<p>Pass</p>									

Note: Table entries are not all inclusive and are for illustration purposes only. This table will typically require more than one page to complete.

As a part of the documentation, a 16-mm movie or a video composite of the test(s) may be prepared to include a title block identifying the test, test conditions, date, and sponsoring agency, before-and-after documentary coverage of the test article and vehicle, and high-speed views of the impact (both profile and overhead).

It is important that the test report contain an ample number of photographs of the pretest, test, and post-test conditions. Additionally, because it is not feasible to include actual photographs in the test report, reproduction techniques used to copy them should produce high quality copies.

Assessment. The impact performance of the test article should be discussed with regard to the three evaluation factors: structural adequacy, occupant risk, and post-impact vehicular trajectory. It is recommended that a summary page(s) be prepared to address each relevant evaluation criteria of Table 5.1. It is recommended that the summary page be as shown in Table 6.2. Note that example entries shown in Table 6.2 are for illustrative purposes only and are not all-inclusive.

A conclusion should be presented as to acceptability of the impact performance of the test article. Recommendations should be offered as to modifications that may improve the impact performance and cost effectiveness of the test article. Recommendations should be categorized as either desirable or essential. Known or predictable limitations of the test article, such as sensitivity to foundation conditions or hazards that would exist

if the test article were improperly oriented, should be given. Recommended applications may also be identified.

6.2 ELECTRONIC DATA

Requirements for documenting and recording electronic test data on a magnetic cartridge have been developed for use on projects sponsored by the Federal Highway Administration (22). Basic test data, such as test number, contract number, and date, and digitized electronic data from onboard transducers are recorded in a specified format. A software package is available from FHWA for entry of the data on the cartridge. These requirements are intended to facilitate and standardize the documentation of data stored in FHWA's Roadside Safety Library (RSL), housed at the Turner-Fairbank Highway Research Center in McLean, Virginia. It is recommended that these requirements be followed, when feasible, and that the data, along with film or video documentation, be submitted to FHWA for entry into the RSL. It is planned that the RSL will serve as a repository for roadside safety data, which can be readily accessed by the highway safety community. The address is as follows:

Federal Highway Administration
Roadside Safety Library (HSR-20)
Turner-Fairbank Highway Research Center 6300 Georgetown
Pike
McLean, VA 22101-2296

CHAPTER 7

IMPLEMENTATION AND IN-SERVICE EVALUATION

7.1 PURPOSE

As mentioned in Chapter 1, in-service evaluation is the final and a key step in the development of a new or extensively modified safety feature. The purpose of in-service evaluation is to determine and document the manner in which the safety feature performs during a broad range of collision, environmental, operational, and maintenance situations for typical site and traffic conditions. The in-service evaluation step is necessary as analytical and crash test experiments described in previous chapters only partially assess the efficacy of a feature and a more thorough and in-depth knowledge of the feature is needed.

Figure 1.1 of Chapter 1 presents a flow chart depicting steps that generally should be followed in the development of a safety feature. Chapter 7 basically covers guidelines for step 9. However steps 7 and 8 should be done prior to initiation of the in-service evaluation. Step 10 is a policy decision made by the appropriate agency (see Section 7.4).

The following sections describe goals and suggested procedures for in-service evaluation. However, it is well understood that the random and extremely complex nature of vehicular accidents coupled with resource limitations of transportation agencies greatly restrict the extent to which these goals can be met and the procedures can be carried out. With few exceptions these studies will be clinical in nature; it will not be feasible to collect sufficient data to develop statistically valid findings. For these reasons, sites must be picked to gain the greatest information within limited time periods and resources.

7.2 OBJECTIVES

In-service evaluation involves the installation of a number of the candidate safety features at carefully selected sites and then the monitoring of the features' performance under "real world" conditions for a period of time. The sites, type, and frequency of information to be acquired and the length of observation period must be selected judiciously and planned to satisfy six objectives:

1. Demonstrate that design goals are achieved in the field and identify modifications that might improve performance.
2. Acquire a broad range of collision performance information on features installed in typical and special situations. Desirably the information would include exposure data and data on occupant injuries and vehicular impact conditions from which severity index values could be defined. In addition to "reported accidents," a measure of the more numerous brush hits and drive-

away collisions should be monitored to establish failure/ success ratio and collision damage repair costs.

3. Identify factors that may compromise or defeat a feature's performance. Examples of such factors include vulnerability of the feature to pilferage or vandalism, accelerated corrosion or degradation of materials due to de-icing salts and other contaminants, and so on.

4. Examine the influence of climate/environment on collision performance. To be determined are the effects, if any, of extremes in heat and cold, ice, snow, rain, wind, and dust on the collision performance and maintenance of the safety feature.

5. Examine the influences that the feature may exhibit on other highway conditions that, in turn, may adversely affect highway operations and traffic. Such factors to be monitored are traffic congestion, change in accident rates or patterns, disruption of surface drainage, or the cause of snow or debris buildup.

6. Acquire routine maintenance information. As a part of this effort, the feature's design and layout should be examined for possible modifications that would lower installation, maintenance, and damage repair costs. Problems encountered during routine maintenance and damage repair should be documented and reported. Note that frequency of repair and repair demand (after both nominal and severe impacts) are critical factors. Systems that can sustain numerous or severe impacts while remaining serviceable offer substantially better protection to motorists than those that are rendered out of service by virtually every impact. This becomes especially critical on high-volume roadways, on roadways where maintenance activities cause congestion and increased risks of accidents, and at problem or high-accident locations. Information of this type often becomes the primary consideration in selection of a barrier system for such locations.

These objectives are general and all may or may not be applicable to a candidate safety feature. Their delineation here is to illustrate the scope and possible type of information that should be acquired.

7.3 CHARACTERISTICS OF TRIAL INSTALLATIONS

To acquire sufficient field information on experimental safety features that will adequately demonstrate their in-service performance, the trial installations may have the following characteristics:

1. The trial period should extend for a minimum of 2 years. This period will expose the hardware to two complete annual climate/environmental cycles. During early stages of the trial,

the local traffic should become familiar with unique appearance of novel designs; thereafter, the affected traffic pattern can return to a more normal state.

2. A sufficient length of installation for a longitudinal barrier, or sufficient numbers of a device for a feature such as an end treatment or a crash cushion, with carefully selected sites, should be determined to provide a number of impacts during the trial period. Potential sites for the new device should be examined and those with a high probability for a collision(s) should be considered for the trial installations. Generally, collision probability increases with traffic volume, proximity of the device to the travel lane, and adverse highway geometrics such as horizontal curvature and grade. The sites should also be selected to expose the feature to the spectrum of impact conditions for which it was intended. Of course, the service requirements of the site must not exceed the service expectations of the device. All collisions, both reported and unreported, are of importance.

3. Each installation should be examined at frequent intervals for the duration of the trial period. The purpose of these site visits is to detect and record minor impacts that might otherwise go unreported. Also to be noted is the state of readiness of the device. Highway maintenance, traffic operations, and law enforcement agencies should be alerted to the test installations and requested to report changes in traffic accident patterns.

4. A new safety feature may be evaluated on a "before/after" basis (a) by gathering accident data for a time period prior to and after installation of the feature, or (b) by gathering accident data for a time period after installation of the feature, and by gathering accident data at a controlled site (without the new feature) during the same time period.

5. An accident/collision reporting technique should be established that will trigger on all impacts even drive-aways. This may entail such techniques as reporting and then painting over or erasing scuff marks.

6. Maintenance forces should perform a field evaluation immediately after construction to determine ease of meeting installation specifications. Maintenance forces should keep costs and labor records on test and control sections. In addition, maintenance personnel could be used to gather drive-away and scuff mark information.

7. At the conclusion of the trial period, an in-service evaluation report should be prepared that presents findings and recommendations. The evaluation report should include a description of site conditions such as roadway geometrics, device location, vehicle operating speeds, vehicle mix, and some measure of exposure. It should also include comments on observed field performance.

7.4 DISCUSSION

Guidelines for in-service performance evaluation of roadside safety features were presented in *NCHRP Report 230* in 1981. It

was recognized that the guidelines were general in nature and would require modification and amplification to suit the type of safety feature and local conditions. Since 1981, Solomon and Boyd (23) have developed a model procedure for evaluating roadside safety hardware that provides more in-depth instructions for in-service evaluation. In addition, Leonin and Powers (24) reported on the in-service evaluation of eight safety features in 14 states.

In the past, FHWA was a key arbiter in establishing acceptability and operational status of new safety features, especially those used on federal-aid highways. Current FHWA policy establishes acceptability of a new safety feature for use on federal-aid projects based on design details, specifications, and crash test results. The decision whether FHWA-accepted features should be deployed as "experimental" or "operational" must now be made by the states.

It is recommended that the developer and user agency of the safety feature develop a detailed plan for the in-service evaluation for review and approval by appropriate authorities prior to initiating the evaluation. Depending on the importance of the device, extent of potential application to a regional or nationwide basis, and funding priorities, the evaluation may be conducted under an extensive federal contract. A cooperative effort of two or more state highway agencies is another feasible evaluation plan. For proprietary devices that are developed using nongovernment funding, it may be appropriate for the owner to sponsor or contribute to the in-service evaluation.

It is recognized that certain design details may be identified during the in-service evaluation that, if properly modified, might improve some aspect of the feature's performance. Such modifications must not be made before their effect on feature safety performance is carefully verified through vehicular crash testing or other appropriate means (see item 10 in Figure 1.1). Past research has shown that seemingly minor variations in design details can adversely affect the safety performance of a feature.

Even after a new or extensively modified feature has successfully passed the in-service evaluation and has been accepted for general use, the operational performance of the feature should continue to be monitored to a lesser degree to enable any flaws or weakness to be corrected or controlled as soon as possible (see item 12 of Figure 1.1). Such weaknesses may be due to conditions that were not anticipated, such as vehicle design changes or different installation site conditions.

Finally, it is important to note that Section 1034 of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) mandates that all states must implement, among other things, a safety management system by fiscal year 1996. It is expected that an in-service evaluation procedure for new and existing roadside safety features will be an integral part of this management system.