NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 230

RECOMMENDED PROCEDURES FOR THE SAFETY PERFORMANCE EVALUATION OF HIGHWAY APPURTENANCES

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- FACILITIES DESIGN
- STRUCTURES DESIGN AND PERFORMANCE
- TRANSPORTATION SAFETY
- VEHICLE CHARACTERISTICS
- (HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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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.

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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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FOREWORD

By Staff
Transportation Research Board

This report is recommended to highway design engineers, bridge engineers, safety engineers, maintenance engineers, researchers, and others concerned with highway safety hardware. It contains a compilation of recommended procedures for evaluating the safety performance of highway appurtenances. These procedures are based on a comprehensive literature review, a state-of-the-art survey, and the advice of a selected group of acknowledged experts. It is believed that this report will contribute to the effort toward providing safer highways.

There is a pressing need for highway engineers to use effective traffic barrier systems. The problem continues to receive urgent attention with development of new systems and improvement of old ones in response to a changing vehicle fleet.

Full-scale impact testing is the most common method of evaluating guardrails, median barriers, bridge railings, crash cushions, and breakaway supports. A number of agencies in the United States are conducting such tests, and there is a need for more uniformity in the procedures and criteria used to evaluate traffic barriers and other safety appurtenances.

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. 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 those questions. The final report was published as "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," *NCHRP Report 153*. It 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 testing procedure.

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 expanded 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.

Project 22-2(4) was initiated in 1979 to address the major changes. Its objective was to review, revise, and expand the scope of *Circular 191* to reflect current technology. This final report on NCHRP Project 22-2(4) consists of three major chapters based on a synthesis of existing information on barrier technology and human tolerance. Chapter Two contains the recommended procedures for testing; Chapter Three covers in-service evaluation; and Chapter Four is a commentary on the rationale for the decisions reflected in the two prior chapters.

In carrying out Project 22-2(4), Southwest Research Institute worked jointly with an *ad hoc* committee of NCHRP Project Panel C-22-2(4) consisting of William A. Goodwin, Tennessee Technological University; Malcolm D. Graham, New York State Department of Transportation; Eric F. Nordlin, California Department of Transportation; James H. Hatton and John G. Viner, Federal Highway Administration; and Hayes E. Ross, Texas A&M University.

An early draft of this document was mailed to some 75 individuals, and comments were received from about 50. The *ad hoc* committee met four times to discuss the various drafts and consider the review comments received. Although the report originated with the research agency, each recommendation has the consensus endorsement of the *ad hoc* committee and NCHRP Project Panel C-22-2(4), which had overall advisory responsibility. Generally, where recommendations are founded on less than clear-cut evidence, the judgment of the advisory groups prevailed.

Parts of this document will need to be revised in the future. For the present, however, it is recommended as the best guide available for adoption by agencies performing or sponsoring research, development, or evaluation of safety appurtenances.

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ACKNOWLEDGMENTS

The work reported herein was performed under NCHRP Project 22-2(4) by the Department of Structural Systems, Southwest Research Institute, San Antonio, Texas. Jarvis D. Michie, Department Director, served as principal investigator.

To a large extent, this report reflects the in-depth traffic barrier technology of more than 75 individuals who participated in the review of drafts and provided source material. This group included representatives from NCHRP Project Panel C22-2(4), TRB Committee A2A04, U.S. Department of Transportation (NHTSA and FHWA), state highway agencies, automobile manufacturers, research agencies, and appurtenance industry. An *ad hoc* group from NCHRP Project Panel C22-2(4), consisting of W. A. Goodwin, Tennessee Technological University; M. D. Graham, New York Department of Transportation; E. F. Nordlin, California Department of Transportation; J. H. Hatton, Jr., and J. G. Viner, Federal Highway Administration; and H. E. Ross, Jr., Texas Transportation Institute, reviewed three preliminary drafts and met with the author on six occasions to discuss report content and recommended changes in the document.

Acknowledgment also is made to M. E. Bronstad, Southwest Research Institute, for his technical contributions.

RECOMMENDED PROCEDURES FOR THE SAFETY PERFORMANCE EVALUATION OF HIGHWAY APPURTENANCES

SUMMARY

Procedures are presented for conducting vehicle crash tests and in-service evaluation of roadside appurtenances. Appurtenances covered by these procedures are (1) longitudinal barriers such as bridge rails, guardrails, median barriers, transitions, and terminals; (2) crash cushions; and (3) breakaway or yielding supports for signs and luminaires. The purpose of the procedures is to promote the uniform testing and in-service evaluation of roadside appurtenances so that highway engineers may confidently compare safety performance of two or more designs that are tested and evaluated by different agencies. These procedures are guidelines that describe how an appurtenance should be tested and evaluated; the selection of specific new, existing, or modified appurtenances for testing and evaluation, the establishment of level of service the appurtenance is to meet, and the establishment of acceptable performance criteria are policy decisions that are beyond the purview of this document. The procedures are directed to the safety or dynamic performance of an appurtenance; other service requirements of economics and aesthetics are not considered here.

These procedures are devised to subject highway appurtenances to severe vehicle impact conditions rather than to "typical" or the more predominant highway situations. Although the innumerable highway site and appurtenance layout 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 appurtenances are often founded in poor or frozen ground. These normalized factors have significant effect on an appurtenance but become secondary in 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 appurtenance to be hit. Vehicle types considered are mini-compact, subcompact, and standard size passenger sedans, intercity and utility type buses, and tractor-trailer cargo trucks. Impact speeds range from 20 to 60 mph (32 to 97 kph), and approach angles vary from 0 to 25 deg. Three appraisal factors are presented for evaluating the crash test performance: structural adequacy, occupant risk, and vehicle after-collision trajectory. Depending on the appurtenance's function, it should contain, redirect, or permit controlled penetration of the impacting vehicle 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 and is measured in terms of the velocity a hypothetical unrestrained occupant strikes the instrument panel or door and the subsequent occupant ridedown accelerations. The after-collision vehicle trajectory is assessed as to the probable involvement of other traffic due to the path or final position of the impacting car. It is recognized that vehicle crash tests are complex experiments and are difficult to replicate due to imprecise control of critical 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 a final stage of development of new or extensively modified appurtenances 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.

CHAPTER ONE

INTRODUCTION

PURPOSE

The purpose of this document is to present uniform procedures to highway agencies, researchers, private companies, and others for crash testing and in-service evaluation as a basis for determining safety performance of candidate appurtenances. Specific questions concerning a device or specific site conditions may require crash test or in-service evaluation conditions other than those recommended in this document. This document is not intended to supersede or override the direct addressing of such needs.

Designation of new, existing, or modified appurtenances to be evaluated by any or all of the procedures and the definition of specific performance criteria for the evaluated appurtenance are to be made by policy setting organizations such as state transportation agencies, American Association of State Highway and Transportation Officials, or the Federal Highway Administration; therefore, these decisions are beyond the purview of this document.

These procedures are intended to update recommendations outlined in *Transportation Research Circular No. 191 (1)*, *NCHRP Report 153 (2)*, and *HRB Circular 482 (3)*.

DEFINITIONS

Highway appurtenances addressed here include longitudinal barriers, crash cushions, and breakaway or yielding supports.

Longitudinal (4) traffic barriers are devices that perform by redirecting errant vehicles away from roadside hazards; examples of longitudinal barriers are guardrails, bridge rails, and median barriers. A typical longitudinal barrier is comprised of length of need, terminals, and, occasionally, transition elements. The length-of-need segment (or midsegment) is established and located such that the trajectory of errant vehicles that leave the pavement under design conditions and that might strike an identified roadside hazard will be intercepted by the segment. Upstream and downstream terminals develop the redirective capacity of the length-of-need segment through tensile and/or flexural anchorage. Transitions occur in longitudinal barrier installations where two systems of different lateral flexibility are joined (e.g., cable to W-beam or W-beam to concrete parapet); generally, a transition is critical only in going from a flexible to a less flexible system, in which case vehicle pocketing may occur.

Crash cushions (4), also called impact attenuators, are intended to safely stop errant vehicles; they may or may not have redirective capability for side impacts. Examples of crash cushions with redirective capability are water cells (with fenders) and steel drums (with fenders); examples of crash cushions without redirective capability are sand containers and an entrapment net.

Breakaway and yielding supports (5) are devices that are designed to readily disengage, fracture, or bend away from impacting vehicles. Such supports are used for signs, luminaires, and other selected highway appurtenances.

PERFORMANCE GOALS

The safety performance objective of a highway appurtenance is to minimize the consequences of a ran-off-the-road incident. The safety goal is met when the appurtenance either smoothly redirects the vehicle away from a hazard zone, gently stops the vehicle, or readily breaks away, without subjecting occupants to major injury producing forces.

Ideally, the roadside should be clear of all obstructions, including safety hardware, and be traversable so that the errant motorist can recover control of the vehicle and stop or return to the pavement. However, there are numerous roadside areas that cannot practically be cleared of fixed objects or made traversable. At these sites, the use of appropriate safety hardware is intended to reduce the consequences of a ran-off-the-road incident.

Safety performance of a highway appurtenance cannot be measured directly but can be judged on the basis of three factors: structural adequacy, occupant risk, and vehicle trajectory after collision.

Structural Adequacy

Structural adequacy as defined and limited to the scope of this report is a measure of geometrical, structural, and dynamic properties of an appurtenance to interact with a selected range of vehicle sizes and impact conditions in a predictable and acceptable manner. Nonvehicle collision-type forces such as wind loads are not included in this evaluation.

Depending on its design function, the appurtenance may perform acceptably through redirection, controlled penetration, or controlled stopping of a selected range of vehicle sizes impacting the installation at specified conditions.

As a result of the test, detached elements, fragments, or other debris from the appurtenance should not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

Occupant Risk

Occupant risk is evaluated according to vehicle responses of accelerations and velocity changes. Relationship between vehicle dynamics and probability of occupant injury and degree of injury sustained is tenuous, because it involves such important but widely varying factors as occupant physiology, size, seating position, restraint, and vehicle interior geometry and padding. Generally, injury occurs when an occupant impacts some element of the vehicle interior abruptly; this is referred to as the "occupant impact." Velocity and attendant severity of the occupant impact are related to the vehicle velocity change experienced during the interval between the vehicle/appurtenance impact and occupant impact. Vehicle accelerations and velocity changes that occur after the occupant impact may also be critical with regard to producing occupant injury.

For occupant risk evaluation, it is required that the vehicle remain upright during and after collision although moderate roll, pitching, and yawing are acceptable. Whereas rollover accidents in general are known to be more likely to involve injuries than nonrollover events, the development of practical appurtenances that meet this vehicle stability requirement has been readily achieved in the past. Moreover, requiring the vehicle to remain upright in the recommended tests has the attendant effect of minimizing vehicle vertical accelerations and vertical velocity changes to subcritical levels in these tests. Thus, vehicle longitudinal and lateral, but not vertical, components of acceleration and velocity change are considered in occupant risk evaluation.

To minimize occupant injury, the strategy is to develop appurtenances that will:

1. For breakaway and yielding supports, minimize velocity change in vehicle. Because of their low mass, the small cars at both low and high impact speeds are the critical tests.

2. For crash cushions, extend velocity change over a long time duration; this implies a low vehicle acceleration. For crash cushions intended to gently stop cars from high speeds, the retarding force developed in the crash cushion must be consistent with low vehicle accelerations in the small-mass cars, while at the same time the crash cushion must possess sufficient energy absorbing capacity to stop large-mass cars. In longitudinal barriers, the event duration is extended and acceleration levels are reduced by providing lateral flexibility in the system or possibly banking the car in rigid shaped barrier collisions.

3. In general, minimize vehicle velocity change prior to occupant impact. After occupant impact, it is believed that the occupant can sustain relatively high vehicle velocity change during the "ride-down" without further undue hazard, assuming that the occupant remains in contact with compartment interior and is not severely "bounced" into other surfaces.

Vehicle Trajectory

After collision, the vehicle trajectory and final stopping position should intrude a minimum distance, if at all, into adjacent or opposing traffic. For longitudinal barrier terminals, vehicle trajectory behind the test article is acceptable in theory since this segment is beyond the warranted length of need.

PERFORMANCE LIMITATIONS

Even the most carefully researched devices have performance limits dictated by physical laws, existing crashworthiness of the vehicles, and limitation of resources. For example, at some gore sites, sufficient space is lacking to gently 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. Some vehicle types may lack necessary crashworthiness features such as interface strength, stiffness, controlled crush properties, and stability to provide occupants with an acceptable level of protection. Barriers that will gently redirect the smaller passenger cars and yet have strength capability to redirect a tractor-trailer or intercity bus are relatively expensive. Even the most advanced systems are not able to handle the full range of traffic that includes motorcycles to trucks carrying special oversize loads. Seemingly insignificant site conditions such as curbs, slopes, and unusual soil properties can defeat a critical appurtenance mechanism and result in a performance failure.

For these reasons, appurtenances are generally developed and tested for selected idealized situations that are intended to encompass the vast majority, but not all, of the possible in-service collisions. Even so, it is essential that test results interpretation be performed by competent researchers and that the evaluation be tempered by sound engineering judgment.

CONTENTS OF REPORT

In Chapter Two, procedures for conducting standardized vehicle crash tests are presented. These procedures include standardized test vehicles and testing conditions, data acquisition tolerances and processing, and general evaluation criteria.

In Chapter Three, an approach to the performance of in-service evaluation of new or extensively modified appurtenances is presented. Characteristics of trial installations along with the type of information to be gathered are discussed.

Chapter Four contains a commentary on Chapters Two and Three that discusses the general rationale for the procedures and presents information on their use. Analytical and experimental tools and techniques that are used in development and evaluation of highway appurtenances are contained in the Appendix.

CHAPTER TWO

VEHICLE CRASH TESTING

PURPOSE

Procedures presented in this chapter deal with testing and evaluating the potential safety performance of roadside appurtenances by crashing passenger and cargo vehicles into them. Safety performance of the test article is evaluated primarily according to measures of the degree of hazard to which the occupants of the impacting vehicle would be subjected and the probable involvement of other nearby traffic. Other service requirements of the appurtenance such as environmental structural requirements, economics and aesthetics, are beyond the scope of these procedures, but certainly must be considered when system designs are assessed.

APPROACH

For each type of appurtenance, a small number of vehicle crash tests are presented to evaluate the test device for a limited range of impact conditions. Many important test parameters have been standardized in order to arrive at the small matrix and to enhance the degree of test replication. Caution should be exercised in the interpretation of test findings and/or projecting the results to in-service performance. The testing agency is encouraged to continue beyond the test matrices presented herein and to address specific site conditions as needed.

TESTING FACILITY

Area

In addition to the space required to accelerate the vehicle to the desired impact speed, the facility should have a sufficient, relatively flat and unobstructed area to provide for unrestricted trajectory of the vehicle following collision. In the collision zone, the surface adjacent to the test installation should simulate a highway shoulder, a bridge deck, or another highway feature as appropriate for the appurtenance being tested. The surface should be flat, with no curbs, dikes, or ditches in front of the installation except when test conditions specify such features.

Soil

For both longitudinal barriers employing soil-embedded posts and breakaway or yielding structures, the embedment soil should be a low-cohesion, well-graded crushed stone or broken gravel with particle size distribution given in Table 1. A strong soil is generally used for longitudinal barrier tests, in particular for the occupant risk assessment. A weak soil may be appropriate for breakaway supports with activation mechanisms that may be adversely affected by weak soil foundation, for barrier transitions and anchorage, and for evaluating barrier pull-down that occurs with post rotation.

TABLE 1. RECOMMENDED SOIL FOUNDATION FOR LONGITUDINAL BARRIER POSTS AND BREAKAWAY OR YIELDING SUPPORTS

Sieve Size	Mass Percent Passing
Strong Soil (S-1)	
50 mm (2 in)	100
25 mm (1 in)	75-95
9.5 mm((3/8 in)	40-75
4.75 mm (No. 4)	30-60
2.00 mm (No. 10)	20-45
0.425 mm (No. 40)	15-30
0.075 mm (No. 200)	5-20
Weak Soil (S-2)	
9.5 mm (3/8 in.)	100
4.75 mm (No. 4)	95-100
1.18 mm (No. 16)	45-80
0.300 mm (No. 50)	10-30
0.150 mm (No. 100)	2-10

For localized use of the recommended soils, the depth and surface radius of the embedment material should be a minimum of 1.5 times the embedment length of the device or post, with a maximum depth and surface radius of 6 ft (1.8 m). The material should be compacted initially, and the disturbed material recompacted between tests to a density of not less than 95 percent maximum dry density; the maximum dry density may be determined by AASHTO T99-70, Method C or D, and the field density may be determined by an appropriate method. A crash test normally should not be performed when the ground is frozen or the soil is saturated with moisture in order to assure repeatability of support foundation unless these factors are a specific part of the test objectives.

Embedment Practice

The method used in embedding test articles should be typical of the intended highway construction practice. Preferably, barrier posts and base bending supports should be inserted in drilled holes and the holes backfilled, although driving the article to depth is permitted; method of construction is to be reported. The footings for breakaway supports should be representative of highway design practice and should be sized for 60-mph (97-kph) wind loading; the footing is considered an integral part of the test article.

Special Structure

An installation simulating the structure and geometry of a bridge deck should be used as a foundation for a bridge rail test to enable assessment of vehicle wheel snagging or potential wheel entrapment beyond the bridge edge.

TEST ARTICLE

General

All key elements or materials in the test article or appurtenance that contribute to its structural integrity or impact behavior should be sampled and tested. To ensure that all critical elements are considered, a careful after-test examination of the tested appurtenance is essential. The material specifications, such as ASTM, AASHTO, etc., should be reported for all key elements. The results of random sample tests should confirm not only that the stated specifications have been met but also that the key elements in the test article were representative of normal production quality (not "Sunday" samples, etc.). The tester should offer a judgment on the effects marginal and over specification materials might have on appurtenance performance. In addition, the 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 installations in actual service and should conform to the 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, and American Institute of Steel Construction bolting procedures should be used. A deviation from fabrication, specification, or erection details should be delineated in the test report.

Installation Details

For tests examining performance of the length-of-need section, the 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, the nonstandard features should be reported. Length of the test section excluding terminals should be at least three times the length in which deformation is predicted, but not less than 75 ft (23 m) for bridge rails and 100 ft (30 m) for guardrails and median barriers. A freestanding barrier, such as a concrete median barrier, which depends on frictional resistance between it and the ground to resist movement should be tested on the same type of ground or pavement surface where it will be used or where it might have the least frictional resistance. For example, loose sand under the concrete barrier may create a ball bearing effect. The type of pavement surface as well as end anchorages or terminals used should be reported.

When testing terminals for longitudinal barriers, the test article should be erected on level grade. A 100-ft (30-m) length-of-need barrier section should be attached to the terminal and anchored at the downstream end.

For tests of a transition joining two barrier systems, the more flexible system (in lateral direction) should be installed in the upstream position. A minimum of 50 ft (15 m) of each of the two barrier systems in addition to the transition should be used; the two systems are to be anchored at their ends.

A rigid, nonyielding backup structure (such as a concrete pier) should be used to simulate a highway feature (such as a bridge pier, elevated gore, or bridge end) when appropriate. For crash cushions which have side hit redirection capability and may have application where they may be struck on one side by direct traffic and on the other side by opposing direction 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.

The breakaway or yielding support should be oriented in the least preferred impact direction (i.e., the direction that theoretically produces the maximum resistance force or energy) consistent with reasonably expected traffic situations. For breakaway or yielding appurtenances designed to function identically when impacted from either direction, testing should verify this feature. The supports should be full-height structures, including sign, call box, or mast arm; an equivalent weight may be substituted for the luminaire.

TEST VEHICLE

Description

The standard vehicles, described in Table 2, are used to evaluate the principal performance factors of structural adequacy, occupant risk, and vehicle trajectory after collision.

The 1800S, 2250S, and 4500S vehicles should be in good condition and free of major body damage and missing structural parts (i.e., doors, windshield, hood, etc.). Special purpose vehicles such as used for highway patrol 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 2250S and 4500S vehicles should have a front-mounted engine; the location and type of transmission is unspecified; the 1800S vehicle should have a front-mounted engine and front-wheel drive. The vehicle bumper should be standard equipment and unmodified for the test; its configuration and height above grade should be reported. The model year of the 1800S, 2250S, and 4500S test vehicles should be within 4 years of the year of test, with a maximum age of 6 years unless otherwise specified.

Five heavy test vehicles are included in Table 2 along with tentative static and dynamic properties. Although several agencies have begun using one or more of these vehicle types, experience accumulated to date is insufficient to clearly establish appropriateness of these vehicles for appurtenance testing or to establish experimentally verified static and dynamic properties for all five heavy vehicles. The heavy test vehicles are presented to encourage research sponsoring or testing agencies to select vehicle types within this group and to adjust their properties to the target values when appurtenance performance with other than, or in addition to, 1800S, 2250S, and 4500S vehicles is desired. It is noted that the number of heavy vehicles is increasing, and it appears that some of current appurtenances may need modification or redesign to handle them adequately.

TABLE 2. STATIC AND DYNAMIC PROPERTIES OF TEST VEHICLES[a]

Designation	1800S	2250S	4500S	20,000P	32,000P	40,000P	80,000A	80,000F
Type	Minicompact Sedan	Subcompact Sedan	Large Sedan	Utility Bus	Small Inter-city Bus	Large Inter-city Bus	Tractor/ Van Trailer	Tractor/ Fluid Tanker
Mass—lb								
Test Inertial[b]	1800 ±50	2250 ±100	4500 ±200	13,800 ±500	20,000 ±750	29,400 ±1000	—	—
Dummy[c]	165	165 ±165	165 ±165	6,200 ±500	6,000 ±1,000	6,000 ±1,000	—	—
Ballast (loose)[d]	0	0	0	0	6,000 ±1,000	4,000 ±1,000	—	—
Gross Static[e]	1950 ±50	2500 ±100	4500±300	20,000 ± 500	32,000 ± 750	40,000 ± 1000	80,000 ±2000	80,000 ±2000
Typical Mass Moments of Inertia[f] lb-ft-s²								
I_{zz}—Yaw	667[h]		4167	48,000		125,000		
I_{yy}—Pitch	496[g]		4625	51,600		156,500		
I_{xx}—Roll	150[g]		—	5,660		23,000		
Typical Center of Mass-in.								
g—Height from grade	19.5	21.8	27.0	41		55.8		
h—From front axle	32.1	40.5	49.8	159		216		
c—Wheel base	87.0	97	121	254		260		
Reference								
DOT-FH	11-9287 11-9486	11-9462	11-8130	11-9462		11-9462		

Notes:

(a) Many of the vehicles and vehicle property requirements are new with this document; hence, typical data have not been measured or reported. Test agencies should measure and report vehicle properties in a format shown in Figures 1 and 2 in Chapter Four. Vehicle masses (test inertial, dummy, ballast and gross static) and center-of-mass location should be physically measured for each test vehicle; mass moments-of-inertia may be acquired from appropriate references for identical vehicle type and loading arrangement.

(b) Includes basic vehicle structure and all components, test equipment and ballast that are rigidly secured to the vehicle structure. This mass *excludes* the mass of anthropomorphic and anthropometric dummies, irrespective of restraint conditions, and ballast and test equipment that are not rigidly secured to the vehicle structure.

(c) For 1800S vehicle, one 50th percentile anthropometric or anthropomorphic dummy is specified; for other vehicle types, occupant mass may be simulated by 50th percentile anthropomotric, anthropomorphic, bags of sand or a combination thereof. See text for position and restraint conditions.

(d) Ballast that simulates cargo and test equipment that is loose or will break loose from tie-down during early stages of appurtenance collision.

(e) Sum of test inertial, dummy, and loose ballast mass; all component masses should be within specified limits.

(f) For vehicle in test inertial condition.

(g) Value for unloaded 1976 Honda Civic (dry fuel tank and mass of 1509 lb); value for 1800S vehicle will be slightly higher.

(h) Value for 1976 Honda Civic (curb mass of 1758 lb) with test instruments but without dummies at 1834 lb.

Vehicle 20,000P is a utility bus with a nonintegral body box and truck chassis and a seating capacity of about 65. The vehicle body, suspension, suspension-to-frame connection, and front bumper should be inspected to verify adequate structural condition. The vehicle bumper should be standard equipment and unmodified for the test; its configuration and height above grade should be reported. The vehicles should have a complete complement of seats for positioning simulated occupants.

Vehicles 32,000P and 40,000P are small and large intercity buses, respectively. The vehicles should be structurally sound; latches for all window and cargo doors on the impact side of the vehicle should be in operable condition. As with the 20,000P utility bus, the intercity buses should have a complete complement of seats.

Vehicle 80,000A is a tractor-trailer, preferably with the trailer being a van. Critical components of the rig such as the tractor bumper and fifth wheel connection must be in good condition. (Non-standard items such as extra fuel tanks should be away from the impact zone if it appears they could affect the vehicle redirection.)

Vehicle 80,000F is a tractor-trailer, preferably with the trailer being a liquid container. Requirements pertaining to 80,000A also apply to 80,000F.

Mass Properties

Vehicle mass properties are important factors in the vehicle/appurtenance collisions. Properties of sprung and unsprung mass, curb mass, test inertial mass, dummy mass, and loose ballast and loose equipment mass are normally considered in some aspect of vehicle testing. For this document, the mass properties of most importance are:

1. *Curb mass*—the standard manufacturer condition in which all fluid reservoirs are filled and the vehicle contains no occupants and cargo. In general, the test inertial mass should not vary significantly from the curb mass.
2. *Test inertial mass*—the mass of the vehicle and all items and test equipment that are rigidly attached to the vehicle structure throughout the appurtenance collision. Mass of dummies, irrespective of the degree of restraint, is not included in the test inertial mass. Test inertial mass is a composite of both sprung and unsprung masses.
3. *Dummy mass*—mass of anthropometric, anthropomorphic, or other simulated occupant loading.
4. *Loose ballast mass*—the mass of simulated cargo and test equipment that is unrestrained or that is likely to break loose from the restraints during the appurtenance collision.
5. *Gross static mass*—the total of the test inertial, loose ballast, and dummy masses.

If needed to bring the test inertial mass within limits of Table 2, fixed ballast may be added in the following manner. Concrete or metal blocks may be positioned in the passenger compartment of passenger sedans and rigidly attached to the vehicle structure by metal straps capable of sustaining loads equivalent to 20 times the blocks' mass. For trucks, the test inertial mass may be adjusted by attaching concrete or steel beams to the truck bed with metal straps capable of sustaining loads equivalent to 10 times the beams' mass. With exception of seats, spare tires, battery, fluids and optional equipment, components should not be removed from the vehicle to meet mass requirements.

Anthropometric or anthropomorphic dummies or sand bags may be used to simulate occupant loading. Anthropometric dummies are 50th percentile male SAE 572 Part B test devices fully instrumented to comply with FMVSS 208. An anthropomorphic dummy may be any 50th percentile male dummy with mass distribution and flexibility similar to the SAE 572 Part B dummy, but it is not necessarily instrumented with accelerometers and femur load cells. Sand in 100 to 150-lb (45 to 78-kg) masses may be packaged in soft cloth, plastic, or paper bags.

With the exception of tests with the 1800S vehicle, use of anthropometric and anthropomorphic dummies is optional. Tests with the 1800S vehicle and preferably with the 2250S vehicle, one anthropometric or anthropomorphic dummy is specified primarily to evaluate typical unsymmetrical vehicle mass distribution and its effect on vehicle stability although the dummy may also, but necessarily, be used to acquire supplementary occupant dynamic and kinematic response data; use of other types of simulated occupant loading is not recommended. Placement of the single dummy is as follows: for redirectional collisions, the dummy should be in the front seat adjacent to the impact side; for off-center, head-on impacts into terminals, crash cushions, or breakaway/yielding supports, the dummy should be in the front seat on the opposite side of the vehicle longitudinal centerline from the impact point. If otherwise not specified, the dummy should be in the driver seat. The dummy is to be unrestrained.

For the 2250S and 4500S vehicles, when one optional dummy is used, the placement and restraint condition are similar to the 1800S vehicle. When two optional dummies are used, the dummy on the opposite side from the impact for redirectional or off-center type of tests should be restrained. For other type tests both dummies should be unrestrained.

For 20,000P, 32,000P, and 40,000P vehicles, passenger loading may be simulated by appropriately sized bags of sand that are positioned unrestrained in all seats. Distribution of passenger loading is to be reported.

Anthropometric or anthropomorphic dummy mass or other simulated occupant loading in any test vehicle, irrespective of restraint condition, is not included in the vehicle test inertial mass.

For cargo trucks, unrestrained bags of sand may be used as loose ballast; distribution of the loose ballast mass is to be reported.

The gross static mass, which is the sum of the test inertial mass, dummy mass, and loose ballast mass, is to be measured and reported.

Speed and Braking

The 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 moved at least two vehicle lengths from the point of last contact with the test article or anticipated final location of breakaway devices. The position of the vehicle at the time of brake application should be reported for each test.

Guidance

The method of guidance of the 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.

TEST CONDITIONS

Test Matrix

The appurtenance test article should be evaluated for dynamic performance according to the minimum matrix of conditions presented in Table 3. Generally, individual tests are designed to evaluate one or more of the principal performance factors: structural adequacy, occupant risk, and vehicle after-collision trajectory. Considerable experience has been accumulated by testing agencies with Table 3 tests that use the 2250S and 4500S type vehicles. Tests that use the 1800S vehicle type are new, and there is no assurance that existing appurtenances or new concepts will be found that fully meet the recommended performance criteria for all the listed tests. In the interim, until sufficient testing experience is acquired with the 1800S type vehicle, the test article must perform acceptably with all appropriate tests using 4500S and 2250S type vehicles and preferably should perform acceptably during tests with the 1800S type vehicle. It may be assumed that test articles performing with 4500S and 1800S type vehicles will also perform acceptably with the 2250S vehicle; thus the 2250S vehicle tests may not need to be performed.

A supplementary crash test matrix is presented in Table 4. In contrast to Table 3 in which an appurtenance class is evaluated by a series of one to six tests, conditions presented in Table 4 should be viewed as individual tests, each of which examines special site condition requirements. Included in the table are structural adequacy tests for multiple service levels (MSL) 1 and 3 (i.e., S14, S15, S31, S32, S46, S47) to supplement or replace corresponding structural adequacy tests in Table 3 (i.e., 10, 30, 40). See Bronstad *(6)* for discussion of the multiple service level approach. Three utility bus tests (S16, S17, and S18) have the purpose of examining the capability of a longitudinal barrier in keeping a large vehicle upright for three levels of impact severity. Test S19 is similar to, but less severe than, test S15 and is included because it corresponds to a number of tests that have been conducted by at least one agency. Tests S20 and S21 are tests to evaluate a barrier's capability in containing a heavy vehicle's cargo as well as the vehicle on the traffic side of the barrier. Test S64 is an intermediate test on breakaway or yielding supports and corresponds to a large percentage of actual roadside collisions. Table 4 test matrix is not intended to be all inclusive and should not dissuade the testing agency from devising other critical test conditions. Moreover, additional tests are recommended to evaluate an appurtenance for nonidealized conditions such as curved installations or nonlevel terrain; such additional tests are discussed in Chapter Four "Commentary."

Impact Conditions Adjustment

Test conditions are sometimes difficult to control. That is, the impact speed and angle and vehicle test inertial mass may vary slightly from recommended values. In addition to placing tolerance limits on each parameter, a composite tolerance limit is presented for the combined effects of the test parameters as determined by the impact severity expression:

$$IS = \frac{1}{2} m(v \sin \theta)^2 \qquad (1)$$

where IS is the impact severity in ft-lb (kJ), m is the vehicle test inertial mass in slugs (kg), and v is the impact velocity in fps (m/s). For tests in which the vehicle is redirected, the angle θ is the impact angle; for the remaining frontal impacts, the angle θ is 90 deg or $\sin \theta$ is 1. To meet the tolerance for a structural adequacy test, target impact speed must be adjusted to compensate for a low or high vehicle test inertial mass. As a general rule, the target impact angle should not be adjusted because the redirection severity is extremely sensitive to this parameter.

For structural adequacy, it is preferable for the actual impact severity IS to exceed the target value rather than undershoot. On the other hand, in low-speed tests where the objective is to determine the lower speed threshold for mobilizing or detaching the appurtenance, it is generally preferable to be on the low side of the target value.

Impact Points

Recommendations are given in Tables 3 and 4 for specific points on the appurtenance where initial vehicle contact should be made. For alternate selection of impact points, the appurtenance should be examined and impacted at the most vulnerable locations. Vulnerable features such as connections and potential snag points may be identified by visual inspection or review of drawings.

DATA ACQUISITION SYSTEMS

Typical Parameters

Parameters to be measured before, during, and after collision are delineated in Table 5 together with measurement tolerances and techniques. Also given are optional parameters that may be monitored.

In the before-test phase, the chief objective of the data acquisition systems is to document the as-built, untested appurtenance and vehicle. Use of photography is suggested.

In the test phase, vehicle impact speed, impact angle, trajectory of vehicle, and accelerations are the most important parameters. Dynamic displacements and strains of the test article may be factors of importance.

After the test, the deformation and damage of both the test article and the vehicle should be documented. Both traffic accident data scale (TAD) *(7)* and vehicle damage index (VDI) *(8)* should be determined.

TABLE 3. CRASH TEST CONDITIONS FOR MINIMUM MATRIX

Appurtenance	Test Designation	Vehicle Type[d]	Impact Speed (mph)	Impact Angle[e] (deg)	Target Impact Severity[f] (ft-kips)	Impact Point[g]	Evaluation Criteria[h]
Longitudinal Barrier[a] Length-of-Need	10	4500S	60	25[i]	$97^{-9,+17}$	For post and beam systems, midway between posts in span contianing railing splice	A,D,E,H,I
	11	2250S	60	15[i]	$18^{-2,+3}$	For post and beam systems, vehicle should contact railing splice	A,D,E,F,(G),H,I
	12	1800S	60	15[i]	$14^{-2,+2}$	For post and beam system, vehicle should contact railing splice	A,D,E,F,(G),H,I
Transition	30	4500S	60	25[i]	$97^{-9,+17}$	15 ft upstream from second system	A,D,E,H,I
Terminal	40	4500S	60	25[i]	$97^{-9,+17}$	At beginning of lenth-of-need	A,D,E,H,I
	41	4500S	60	0[i]	$541^{-53,+94}$	Center nose of device	C,D,E,F,(G),H,J
	42	2250S	60	15[i]	$18^{-2,+3}$	Midway between nose and lenth-of-need	C,D,E,F,(G),H,I,J
	43	2250S	60[o]	0[i]	$270^{-26,+47}$	Offset 1.25 ft from center nose of device	C,D,E,F,(G),H,J
	44	1800S	60	15[i]	$14^{-2,+2}$	Midway between nose and length-of-need	C,D,E,F,(G),H,I,J
	45	1800S	60[o]	0[i]	$216^{-21,+37}$	Offset 1.25 ft from center nose of device	C,D,E,F,(G),H,J
Crash Cushion[b]	50	4500S	60	0[j]	$541^{-53,+94}$	Center nose of device	C,D,E,F,(G),H,J
	51	2250S	60[o]	0[j]	$270^{-26,+47}$	Center nose of device	C,D,E,F,(G),H,J
	52	1800S	60[o]	0[j]	$216^{-21,+37}$	Center nose of device	C,D,E,F,(G),H,J
	53[l]	4500S	60	20[j]	$63^{-6,+11}$	Alongside, midlength	C,D,E,H,I,J
	54	4500S	60	10-15[j]	$541^{-53,+94}$	0-3 ft offset from center of nose of device	C,D,E,F,(G),H,J
Breakaway or Yielding Support[c]	60	2250S	20	[k]	$30^{-4,+4}$	Center of bumper[m,n]	B,D,E, F,(G),H,J
	61	2250S	60	[k]	$270^{-26,+47}$	At quarter point of bumper[n]	B,D,E,F,(G),H,J
	62	1800S	20	[k]	$24^{-3,+3}$	Center of bumper[m,n]	B,D,E,F,(G),H,J
	63	1800S	60	[k]	$216^{-21,+37}$	At quarter point of bumper[n]	B,D,E,F,(G),H,J

(a) Includes guardrail, bridgerail, median and construction barriers.
(b) Includes devices such as water cells, sand containers, steel drums, etc.
(c) Includes sign, luminaire, and signal box supports.
(d) See Table 2 for description.
(e) + 2 degrees
(f) IS = $1/2\, m\, (v \sin \theta)^2$ where m is vehicle test inertial mass, slugs; v is impact speed, fps; and θ is impact angle for redirectional impacts or 90 deg for frontal impacts, deg.
(g) Point on appurtenance where initial vehicle contact is made.
(h) See Table 6 for performance evaluation factors; ( ) denotes supplementary status.
(i) From centerline of highway.
(j) From line of symmetry of device.
(k) Test article shall be oriented with respect to the vehicle approach path to a position that will theoretically produce the maximum vehicle velocity change; the orientation shall be consistent with reasonably expected traffic situations.
(l) See Commentary, Chapter 4 Test Conditions for devices which are not intended to redirect vehicle when impacted on the side of the device.
(m) For base bending devices, the impact point should be at the quarter point of the bumper.
(n) For multiple supports, align vehicle so that the maximum number of supports are contacted assuming the vehicle departs from the highway with an angle from 0 to 30 deg.
(o) For devices that produce fairly constant or slowly varying vehicle accelerations; an additional test at 20 mph (32 kph) is recommended for staged devices, those devices that produce a sequence of individual vehicle deceleration pulses (i.e. "lumpy" device) and/or those devices comprised of massive components that are displaced during dynamic performance (see commentary).

TABLE 4. TYPICAL SUPPLEMENTARY CRASH TEST CONDITIONS

Appurtenance	Test Designation	Vehicle Type[d]	Impact Speed (mph)	Impact Angle[e] (deg)	Target Impact Severity[f] (ft-kips)	Impact Point[g]	Evaluation Criteria[h]
Longitudinal Barrier[a] Length-of-Need	S13	1800S	60	20[i]	$25^{-2,+4}$	For post and beam system, at mid span.	A,D,E,H,I
	S14[p]	4500S	60	15[i]	$36^{-4,+6}$	For post and beam system, vehicle should contact railing splice.	A,D,E,H,I
	S15[q]	40,000P	60	15[i]	$237^{-23,+41}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S16[r]	20,000P	45	7[i]	$14^{-2,+3}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S17[r]	20,000P	50	15[i]	$77^{-9,+16}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S18[r]	20,000P	60	15[i]	$111^{-11,+19}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S19	32,000P	60	15[i]	$97^{-9,+17}$	For post and beam system, vehicle should contact railing splice.	A,D,E
	S20[s]	80,000A	50	15[i]	[t]	For post and beam sytem, vehicle should contact railing splice.	A,D[s]
	S21[s]	80,000F	50	15[i]	[t]	For post and beam system, vehicle should contact railing splice.	A,D[s]
Transition	S31[p]	4500S	60	15[i]	$36^{-4,+6}$	15 ft upstream from second system	A,D,E,H
	S32[q]	40,000P	60	15[i]	$237^{-23,+41}$	15 ft upstream from second system	A,D,E
Terminals	S46[p]	4500S	60	15[i]	$36^{-4,+6}$	At beginning of length-of-need	A,D,E,H
	S47[q]	40,000P	60	15[i]	$237^{-27,+41}$	At beginning of length-of-need	A,D,E
Crash Cushion[b]	(NONE)						
Breakaway or Yielding Support[c]	S64	1800S	40	[k]	$96^{-14,+15}$	Center of bumper[m,n]	B,D,E,F,(G),H,J

For notes (a) through (o), see Table 3.

(p) Multiple Service Level 1 structural adequacy test; see Commentary, Chapter 4.

(q) Multiple Service Level 3 structural adequacy test; see Commentary, Chapter 4.

(r) Utility bus stability test; S16 for Multiple Service Level 1 appurtenance; S17 for Multiple Service Level 2 appurtenance; S18 specified for Multiple Service Level 3 appurtenance.

(s) Cargo/debris containment test; vehicle, cargo, and debris shall be contained on traffic side of barrier.

(t) Not appropriate for articulated vehicles.

TABLE 5. DATA ACQUISITION METHODS

Phase	Parameter	Measurement Tolerances	Acceptable Techniques	Remarks
Pretest	Test article installation	±0.02 ft (±6 mm)	General surveying equipment. Photography	Post spacing, rail heights, alignment, orientation, etc., are critical items.
	Mass of vehicle and onboard elements	±1%of items but not more than ±20 lb (±9 kg)	Commercial scales	Mass distribution of vehicle as tested.
	Geometry of vehicle	±0.02 ft (±6 mm)	Common scales	See Chapter 4, Figures 1 and 2 for critical items.
Test	Impact speed(1)	±0.2 mph (±3.2 kph)	(a) Contact switches speed trap (b) High-speed cine (c) Radar (d) Fifth wheel	Minimum film speed of 500 fps.
	Vehicle accelerations	Longitudinal Barriers and Crash Cushions ±0.20 g Breakaway and Yielding Supports ±0.10 g	(a) Accelerometers	Lateral and longitudinal (and preferable vertical) accelerometers attached to a common mounting block and the block attached to the vehicle floor structure on vehicle centerline at center of vehicle gross weight distribution (longitudinal). A second set of accelerometers is a desirable option. Complete data system responsive to 0-min. 500 Hz signal. Raw data recorded on magnetic tape and maintained as permanent record. Data may be filtered for visual presentation according to SAE J211b Channel Class 180.
			(b) High-speed cine(2)	Minimum film speed of 500 fps. Internal or external timing device; stationary references located in field of view of at least two cameras positioned 90 deg apart. Layout and coordinates of references, camera positions, and impact point should be reported. Two vehicle references are to be located on the vehicle roof, one positioned directly above the vehicle center of mass and the second 5.0 ft (1.5 m) to the rear for the standard car and 4.0 ft (1.2 m) for the small car. Instant of impact should be denoted by a flash unit placed in view of data cameras. The instant of impact should also be recorded on magnetic tape or oscillograph.
	Vehicle trajectory and roll, pitch, and yaw	±0.5 ft (0.15 m) ±0.5 deg	(a) High-speed cine	Minimum film speed of 200 fps. Overhead and end views of installation preferred.
	Occupant (a) Kinematics	(Not Applicable)	Anthropomorphic or anthropometric device and on-board cine	Onboard movie camera should have minimum film speed of 64 fps with view of dummy from rear over inside shoulder. As a minimum, the dummy should have gross mass distribution and gross joint movements of a 5th percentile female, 50th or 95th percentile male surrogate.
	(b) Dynamics	1.0 g's ±100 lb (45 kg)	Anthropometric device	50th percentile male conforming to Part 572 of Title 49 of the Code of Federal Regulation. Dummy instrumentation should conform to FMVSS 208.
	(c) Risk	±1.0 g's	Vehicle accelerometers	See vehicle accelerations; applicable to 1800S, 2250S or 4500S vehicle test only.
	Test article dynamic strain (Optional) Test article dynamic deformation.	±100 in./in. ±0.08 ft (24 mm)	Resistance strain gage High-speed cine	System responsive to 0-min. 300 Hz. Data recorded by oscillograph or on magnetic tape. Overhead camera view: minimum film speed of 200 fps.
Posttest	Test article permanent deformation/final position	0.02 ft (6 mm)	General surveying equipment	Location of significant debris reported.
	Test article/vehicle damage	(Not applicable)	Visual inspection, VDI and TAD	TAD standard photographs should be shown in report.

(1) Speed measured during vehicle approach at a maximum 15 ft (4.6 m) from point of impact.
(2) To be used only as a backup or secondary system due to uncertainty in data processing attributed to a double differentiation calculation.

Additional Requirements

The parameters cited in the foregoing paragraphs and the data acquisition systems should not be considered all-inclusive. Other parameters peculiar to an appurtenance or to its expected application may entail additional techniques.

PERFORMANCE EVALUATION

Potential safety performance of highway appurtenances may be inferred from guidelines given in Table 6. Three dynamic performance evaluation factors are given in Table 6 together with applicable appurtenances and suggested evaluation criteria; the factors are (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory after collision.

Whereas suggested evaluation criteria are given in Table 6 and discussed in the following paragraphs, these criteria are intended as general guidelines and are not necessarily those accepted by AASHTO, FHWA, or other transportation agencies.

It should be noted that costs (i.e., installation, maintenance, damage repair, etc.), aesthetics, and other service requirements are not evaluated.

Structural Adequacy

Structural adequacy is generally the first factor to be evaluated, and the appurtenance should perform successfully according to the requirements presented in Table 6. Otherwise the appurtenance may present a more severe and unpredictable roadside hazard than the roadway without the appurtenance. Depending on its intended function, the appurtenance may satisfy structural adequacy by redirecting or stopping the vehicle or permitting the vehicle to break through the device.

Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.

Although not addressed in this report, the appurtenance must satisfy the provisions of the structural design specifications for wind and other environmental considerations when applicable.

Occupant Risk

A number of factors (such as compartment geometry, padding, occupant restraints, and inherent stability of the vehicle) are outside the control of highway engineers. To remove the variability of these factors from appurtenance evaluation, occupant risk is appraised according to either vehicle accelerations or velocity change as these indices are functions of only the appurtenance design and vehicle external structure. Whereas the highway engineer is ultimately concerned with safety of the vehicle occupants, the occupant risk criteria (Table 6) should be considered as the guidelines for generally acceptable dynamic performance. These criteria are not valid, however, for use in predicting occupant injury in real or hypothetical accidents.

A first requirement for occupant risk evaluation is for the impacting vehicle to remain upright during and after the collision, although moderate roll, pitching, and yawing are acceptable. This requirement has the effect of minimizing the vertical components of vehicle accelerations and velocity change; thus these components are not normally measured and evaluated in typical crash tests. Although it is preferable that all vehicles remain upright, this requirement is applicable only to the tests involving the 1800S, 2250S, and 4500S vehicles and to the special vehicle stability tests in Table 4.

Occupant risk is then indicated by the projected forward and lateral reactions and dynamics of a hypothetical unrestrained front seat occupant who is propelled through the compartment space by vehicle collision accelerations; strikes the instrument panel, windshield, or side structure; and then subsequently is assumed to experience the remainder of the vehicle collision acceleration pulse by remaining in contact with the interior surface. The two performance factors are (1) the occupant-compartment impact velocity and (2) highest 10 ms occupant (and vehicle) acceleration average for remainder of collision pulse beginning at the occupant/compartment impact. Generally, low values for these factors indicate less hazardous appurtenances. To be noted is that while a dummy may be specified for a test, its dynamic and kinematic responses are not required or used in this occupant risk assessment; hypothetical occupant compartment impact velocity and ride down accelerations are calculated from vehicle c.g. accelerations. Methods for calculating values for these factors are presented in Chapter Four, under "Performance Evaluation."

Threshold and acceptable levels for occupant risk are given in Table 6 as a function of appropriate acceptance factors, F. Establishment of acceptance factors is a policy decision and, therefore, beyond the scope and purview of the document. However, recommended values are given in "Commentary," Chapter 4, Table 8.

Vehicle Trajectory

Vehicle trajectory hazard (Table 6) is a measure of the potential of after-collision trajectory of the vehicle to cause a subsequent multivehicle collision or subject vehicle occupants to undue hazard. After collision, the vehicle trajectory and final stopping position should intrude a minimum distance, if at all, into adjacent or opposing traffic lanes.

In tests where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, the vehicle speed change during tests article contact should be less than 15 mph (24 kph) and the exit angle from the test article should be less than 60 percent of the impact angle. For certain classes of appurtenances, vehicle trajectory behind the test article is acceptable.

REPORT

A report should include, but not be limited to, the following sections:

1. *Appurtenance Description.* The test article should be fully described, with engineering drawings and material specification. Reference should be made to revisions in the design evaluated in the earlier tests. Of particular importance is the delineation of special fabrication and installation procedures (such as heat treatment, weldments, and bolt tension, galva-

TABLE 6. SAFETY EVALUATION GUIDELINES

Evaluation Factors		Evaluation Criteria	Applicable to Minimum Matrix Test Conditions (see Table 3)
Structural Adequacy	A.	Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	10, 11, 12, 30, 40
	B.	The test article shall readily activate in a predictable manner by breaking away or yielding.	60, 61, 62, 63
	C.	Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle	41, 42, 43, 44, 45, 50, 51, 52, 53, 54
	D.	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	All
Occupant Risk	E.	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	All
	F.	Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. (0.61m) forward and 12 in. (0.30m) lateral displacements, shall be less than: Occupant Impact Velocity-fps Longitudinal: $40/F_1$; Lateral: $30/F_2$ and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations—g's Longitudinal: $20/F_3$; Lateral: $20/F_4$ where F_1, F_2, F_3, and F_4 are appropriate acceptance factors (see Table 8, Chapter 4 for suggested values).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
	G.	(Supplementary) Anthropometric dummy responses should be less than those specified by FMVSS 208, i.e., resultant chest acceleration of 60g, Head Injury Criteria of 1000, and femur force of 2250 lb (10 kN) and by FMVSS 214, i.e., resultant chest acceleration of 60 g, Head Injury Criteria of 1000 and occupant lateral impact velocity of 30 fps (9.1 m/s).	11, 12, 41, 42, 43, 44, 45, 50, 51, 52, 54, 60, 61, 62, 63
Vehicle Trajectory	H.	After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	All
	I.	In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.	10, 11, 12, 30, 40, 42, 44, 53
	J.	Vehicle trajectory behind the test article is acceptable.	41, 42, 43, 44, 45, 50, 51, 53, 54, 60, 61, 62, 63

nizing in critical stressed areas, etc.) that may influence the dynamic behavior.

2. *Test Procedures.* A complete description of the test facility and associated equipment should be contained in the report. When appropriate, soil properties and conditions should be reported. The data acquisition systems should be fully described, together with the procedures used in calibrating and processing the data. The report should include complete drawings and specifications for any recommended designs.

3. *Findings.* To facilitate comparison of findings from two or more testing agencies, a findings presentation format, as shown in Table 7, is recommended. As a part of the report, a 16-mm color movie may be prepared that will include before-and-after documentary coverage of the test article and vehicle, high-speed data views of the impact (both profile and overhead), and a title block identifying the test and test conditions.

4. *Evaluation.* The dynamic performance of the test article should be discussed with regard to the three evaluation factors: structural adequacy, occupant risk, and vehicle trajectory. A conclusion should be presented as to acceptability of the dynamic performance of the appurtenance. Recommendations should be offered as to modifications that may improve the article and to situations where the article may be applicable. It would be helpful to categorize the offered recommendations as either desirable or essential.

5. *Identification.* The test report should include the name and address of the testing organization, responsible personnel, location of test facility, and the date of the test.

CHAPTER THREE

IN-SERVICE EVALUATION

PURPOSE

In-service evaluation is a final stage of development of new or extensively modified highway safety appurtenances. Safety appurtenance hardware that has been designed and analyzed, is judged to perform acceptably during vehicle crash tests or through other acceptable procedures, and exhibits potential for performing acceptably in service is introduced into service on a trial basis and the installations are extensively monitored. The in-service evaluation is intended to avoid the creation of widespread unsuspected problems because of the introduction of a new appurtenance. The urgency with which the promised performance of the new appurtenance is needed and the probability of its successful performance should be weighed in determining the extent of the trial stage.

The purpose of the in-service evaluation is to determine the manner in which the appurtenance performs during a broad range of collision, environmental, operational, and maintenance situations for typical site and traffic conditions. The in-service evaluation phase is recognition of the fact that analytical and experimental efforts cannot completely evaluate a new device because of practical and economical limitations. Sometimes subtle and complex combinations of environmental and impact factors can defeat or degrade the safety performance of a device. The final judgment of a new device should await a device's performance in the "real world." A new device will desirably be selected for in-service evaluation only after it has demonstrated acceptable performance during dynamic testing and shows promise of performing acceptably in actual service.

At the conclusion of the evaluation period, one of the following actions may be taken:

1. Accept the appurtenance for general service.

2. Accept the appurtenance for restricted service.

3. Extend the evaluation period for additional observation.

4. Recommend modifications to appurtenance hardware and return to development/crash testing stage.

5. Recommend appurtenance be removed from service.

OBJECTIVES

There are six important objectives of the in-service performance evaluation. The site of trial installations and type and frequency of information to be gathered should be selected judiciously and planned to satisfy requirements:

1. Determine if design goals are achieved in field and identify details that if properly modified might improve field performance.

2. Acquire a broad range of collision performance information on devices installed in typical and special situations. In addition to "reported accidents," a measure of the more numerous brush hits and drive-away collisions should be monitored in order to establish the failure/success ratio. Vehicle collision damage is an important part of cost.

3. Identify special problems that may compromise or defeat appurtenance performance. Examples of special problems include vulnerability of device to pilferage or vandalism, accelerated corrosion or degradation of materials due to deicing salts and other contaminants, etc.

4. Examine 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 appurtenance.

5. Examine influence that device exhibits on other highway conditions that in turn may adversely affect highway operations and/or traffic. Such features to be monitored are traffic congestion, change in accident rates or patterns, disruption of efficient surface drainage, or the cause of unusual snow buildup.

6. Acquire routine maintenance information. As a part of this effort, the hardware design and layout should be examined for possible modifications that would lower installation,

TABLE 7. FINDINGS FORMAT

Item	Description	Format	Scale (units/in.)	
			Ordinate	Abscissa
Photography				
Still	Before and after test of vehicle and installation	Photographs		
Movie	Sequence (4 to 8 frames) during impact	Photographs		
Acceleration				
Vehicle	Lateral and longitudinal; filtered (see Table 5)	Plots[a]	10 g[b]	100 ms
Dummy	Chest and head x, y, and z; filtered (SAE J211b)	Plots	20 g	100 ms
Force[c]				
Seat Belt	Lap and shoulder harness	Plots	1000 lb (4448 N)	100 ms
Femur	Femur force cells	Plots	1000 lb (4448 N)	100 ms
Dynamic	Strain gage data from critical appurtenance points	Plots	500 μ in./in	100 ms
Strain[c]	Drawing showing strain gage locations	Drawing		
Deformation				
Permanent	Profile of deformation	Table		
Dynamic	Maximum deformation of test article	Text		
Damage Estimate	Appurtenance length, elements or components required to restore installation. Vehicle exterior and passenger compartment deformation.	Description Photographs VDI Scale TAD Scale		

Notes:

(a) Data from film analysis may be presented in tabular form.

(b) For base-bending signs, the ordinate should be 2 g/in.

(c) Optional.

maintenance and/or damage repair costs. Problems encountered during routine maintenance and damage repair should be noted and reported.

These objectives are general and all may or may not be applicable to a new device. Their delineation here is to illustrate the scope and possible types of information that should be acquired.

CHARACTERISTICS OF TRIAL INSTALLATION

In order to acquire sufficient field information on experimental safety appurtenances, the trial installations may have the following characteristics:

1. The trial period should extend preferably for 2 years. This 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. Any adverse effects of drivers to a new appurtenance should be noted.

2. Sufficient length of installations/number of devices coupled with carefully selected sites should be determined to provide a number of collision impacts during the trial period. Potential sites for the new device should be examined and those with the highest probability for a collision should be selected 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. 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. 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, traffic operations, and law enforcement agencies should be alerted to the test installations and requested to report changes in traffic accident patterns.

4. To evaluate a new appurtenance on a relative basis, the trial period should be begun before the installation for a before/after comparison or the trial installation sites should be compared to control sites.

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.

DISCUSSION

Although several state highway agencies have performed in-service evaluation of new appurtenances, the guidelines presented in this section are new and have been established to promote a more consistent and thorough examination of safety devices. It is recognized that modification to the guidelines will be required to suit local conditions and device purposes. Common sense and sound engineering judgment should be used in developing the in-service evaluation plan.

Because in-service evaluation may involve several groups and organizations, the task should be carefully planned and coordinated. Within a highway agency, the following groups may be involved in the evaluation:

Research
Design
Traffic Operations
Construction
Maintenance

For accident investigation, the NHTSA National Accident Sampling System (NASS) may be of use along with local assistance from law enforcement, medical, and other emergency groups.

Depending on the importance of the device, extent of potential application to a regional and/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.

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 appurtenance performance. Such modifications must not be made before their effect on appurtenance safety performance is carefully verified through vehicle crash testing or other appropriate means. Past research has shown that seemingly minor variations in design details can adversely affect the safety performance of barriers *(4)*.

At the conclusion of the evaluation period or a suitable interval if the period is not defined, a report containing findings, conclusions, and recommendations should be prepared.

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

CHAPTER FOUR

COMMENTARY

SCOPE

The primary purpose of the recommended procedures is to present uniform crash testing and in-service evaluation practices whereby highway engineers may have a basis for comparing the relative safety performance merits of two or more candidate appurtenances.

VEHICLE CRASH TESTING

Limitations

Vehicle crash tests are complex experiments and are difficult to replicate because of imprecise controls of critical test conditions (i.e., impact speed, angle, etc.) and the sometimes random and unstable behavior of dynamic crush and fracture mechanisms. The testing procedures are intended to enhance the precision of these experiments while maintaining their costs within acceptable bounds. The highway engineer should recognize the limitations of these tests and exercise care in interpreting the results.

Idealized Conditions

If one considers the innumerable highway site and appurtenance layout conditions that exist, it is impractical or impossible to duplicate these in a limited number of standardized tests. Accordingly, the aim of the procedures is to normalize or idealize test conditions. Hence, straight longitudinal barriers are tested, although curved installations exist; a flat grade is recommended, even though installations are sometimes situated on sloped shoulders and behind curbs. These normalized factors have significant effect on a barrier's performance and may obscure serious safety deficiencies that exist under more typical but less ideal conditions. However, these normalized factors are thought to be secondary in importance when the object of a test program is to compare the results of two or more systems. Moreover, the normalized conditions are more easily duplicated by testing agencies than, say, a unique feature; consequently, they should promote correlation of results from different groups. Nevertheless, when the highway engineer requires the performance of a system for specified site conditions (such as a unique soil or curb layout) or the performance of an appurtenance is suspected of being unacceptable under some likely conditions, it is important that these conditions should be used instead of, or in addition to, the idealized conditions.

Permanent or Temporary Appurtenances

These procedures are intended for use with highway appurtenances that will be permanently or temporarily installed along the highway.

Temporary appurtenances are generally used in construction zones or other temporary locations. An important additional characteristic of a construction zone is the exposure of construction personnel to errant traffic. Thus, a barrier in a construction zone may be required to (1) redirect errant traffic away from a roadside hazard or other traffic and (2) to shield construction workers from errant vehicles. Depending on specific site conditions, potential collision severity may equal or even exceed conditions found at typical nonconstruction zone sites.

A crash cushion attached to the rear of maintenance trucks or trailer-mounted is a special case and is not specifically addressed by the test matrix in Table 3. However, Tests 50 and 54 with impact speed reduced to 45 mph (72 kph) and Tests 51 and 52 at the 60-mph (97-kph) recommended speed are suggested. Although it is desirable to develop crash cushions for maintenance vehicles for the full 60-mph performance, the state of the art has not advanced to this point at this time. Accordingly, for the interim, the previously noted 45-mph (72-kph) tests are recommended. The truck should be in second gear, and the brakes on the maintenance trailer and/or truck should be locked. In addition to occupant risk requirements for the impacting vehicle, the trailer/truck skid distance should be reported.

Complementary Techniques

Structural test and analytical procedures are available for use in lieu of, or in addition to, vehicle crash testing. Conventional structural analysis and design techniques are most useful in early development stages of an appurtenance. Computer simulations of the vehicle/appurtenance dynamic interactions are useful in evaluating the appurtenance for a wide range of impact conditions. Pendulum and bogie vehicle tests have proved to be useful in evaluating luminaire and sign supports and in certain studies of barrier components of full assemblies, and the potential for obtaining valuable insight from simple static tests of components and assemblies should not be overlooked. A discussion of these complementary procedures is presented in the Appendix. The intent of this section is to make the appurtenance designer/developer aware of available tools so that he may select the most cost-effective approach or combination of tools.

This report does not endorse or approve any one test method, procedure or analytical technique, or suggest that one procedure is equivalent to another. Rather, the basic position is that if a decision has been made to use a procedure, such as full-scale vehicle crash testing, the designer/developer/tester should follow as closely as practical the procedures that are recommended. Acceptability of one of the complementary techniques in lieu of, or in addition to, full-scale crash testing is a policy decision and is beyond the purview of this report.

TESTING FACILITY

As discussed previously, features of the impact zone are idealized for the general performance type of test. That is, the surface should be flat, with no curbs, dikes, or ditches in front of the installation.

The dynamic and structural behavior of many appurtenances, founded in soil along the highway, depend on the degree of support or fixity provided by the soil. Thus, the soil foundation is a vital part of the appurtenance system and must be considered in the dynamic performance evaluation. The recommended soils are well-graded materials that should be readily available to most testing agencies. Soil S-1 is a selected AASHTO base that compacts to a strong foundation material. Soil S-2 is a typical AASHTO fine aggregate and will provide a weaker foundation for the appurtenance. The low-cohesion material with minimum fine particles should exhibit minimum sensitivity to moisture content and thixotropy; hence, the material will be readily amenable for rapid recompaction between tests to the referenced condition. Factors to be considered in selecting the appropriate type of soil are discussed under "Test Article."

A structure simulating a bridge is suggested for bridge rail tests for two reasons. First, the behavior of the bridge deck during impact can be observed; second, the vehicle trajectory during redirection can be monitored to observe any undesirable performance such as when a vehicle wheel drops below deck level and is trapped. If the bridge deck strength is believed critical to the barrier performance, the structural design should be representative of appropriate existing bridge decks; the structural design details should be reported.

TEST ARTICLE

Construction Details

Failure or adverse performance of a highway appurtenance during crash testing can often be attributed to seemingly insignificant design or construction details. For this reason, it is most important to assure that the test article has been properly assembled and erected and that critical materials have the specified design properties. Details of most concern are those that are highly stressed (such as welded and bolted connections, anchor cables, cable connections, and concrete footings) or those that must fracture or tear away during impact (such as transformer bases or weakened barrier posts). Compressive tests of concrete cylinders, proof tests of cable assemblies, and tensile tests of metal coupons, should be performed on a random sample of the test article elements. Even though well-defined material specifications and appropriate fracture modes may not be fully developed, the properties of all material used in the test article should be documented in detail.

Installation Length

The test engineer must exercise proper judgment in establishing test installation length. In specifying minimum length of longitudinal barrier installation, the intent is to minimize influence of terminals and thereby simulate a long barrier. Also to be considered is the possible need to extend the barrier installation to observe a second collision between vehicle and barrier.

Complete Test Article

For breakaway and yielding appurtenances, the detached elements represent a potential hazard to other traffic; consequently, the full-height structure should be employed as the test article in order that a realistic detached element trajectory may be observed. Also, it is recognized that the mast arms and luminaire (i.e., mass) may affect the fracture mechanism of the yielding or frangible part due to dead load; therefore, these components are required to promote an acceptable correlation between tests and service experience. The luminaire may be simulated by an equivalent mass.

Orientation

The energy or force required to fracture a breakaway device is sometimes sensitive to orientation of the device with respect to direction of impact. For example, pendulum tests have indicated that a breakaway transformer base breaks more readily when struck on a corner than on a flat side. Because errant vehicles may approach a breakaway device at angles ranging from 0 to 30 deg or more, it is suggested that the device be tested assuming the most severe direction of vehicle approach consistent with expected traffic conditions. For instance, the transformer base should be oriented so the vehicle strikes a flat side. Moreover, because the energy required to fracture a device can be increased due to buckling of the support at the point of contact with the vehicle, the handhole in the luminaire shaft should be positioned during a test so that probability of local collapse of the shaft is maximized *(5)*.

Foundation Details

Dynamic performance of most guardrails and breakaway or yielding supports and some median barriers depends on the strength and fixity of the soil foundation. The soil foundation is an integral part of such appurtenance systems. For example, displacement and/or rotation of a breakaway device footing during collision can adversely affect the fracture mechanism. Insufficient soil support can lead to excessive guardrail post movements and guardrail lateral deflection during vehicle collision and result in a lower system capacity to contain and redirect errant vehicles. Insufficient soil strength can also be a critical and limiting factor for the anchoring function of a guardrail or median barrier terminal. On the other hand, an unusually firm soil can increase the lateral stiffness of a longitudinal barrier and subject occupants of colliding vehicle to undue hazard.

Soil condition along the highway is a variable. Strength is a function of soil type and ranges from soft sand materials to hard rock materials; moreover, the soil type may vary considerably within a locale as well as from region to region. Soil strength may also be a function of the season as it can be significantly affected by moisture content and whether it is frozen. The testing agency should be aware of the importance of soil strength and select the most appropriate soil type consistent with the potential application of the appurtenance.

Two soils are presented in Table 1; both are low-cohesion type materials to facilitate the rapid recompaction to standard conditions between tests. Soil S-1 is almost identical to the material recommended in *TRC No. 191 (1)* and is considered the "strong" soil with respect to lateral support of embedded post. Soil S-2 is a new material without reported test experience and is considered the "weak" soil with respect to lateral support of embedded posts.

The following soil type selection criteria are given to provide the testing agency with general guidance:

Soil S-1 (Strong)

Length-of-need, transition, and terminals of longitudinal barriers. A large percentage of previous testing has been performed in soil similar to S-1, and a historical tie is needed. Although S-1 is probably stronger than the average condition found along the roadside, it is still representative of considerable amount of existing installations. Unless the test article is to be limited to areas of "weak" soils, soil S-1 should be used, in particular, for the occupant risk tests.

Soil S-2 (Weak)

Breakaway or yielding supports for most test devices; terminals that may be sited in weak soil regions; length-of-need and transition segments that may be sited in weak soil regions.

Preferably, longitudinal barrier elements should be evaluated for both soil types, but this approach may not be practical.

In addition to soil selection, the footing for a breakaway device should be designed for the maximum wind condition of 60 mph, thus yielding a minimum footing mass and size; a larger footing will yield a greater breakaway device fixity and, hence, is less critical. A gap (not simulated in the test) between the soil and footing of in-service devices caused by soil shrinkage or wallowing caused by wind is believed to adversely affect breakaway performance.

Realistic Site Conditions

Conditions for testing crash cushions should be in keeping with expected use of the device. That is, while the cushion requires validation for side impacts as well as for end-on impacts, certain devices do not fit the general pattern of site conditions, and special considerations must be given for these situations. For example, the dragnet does not have an exposed side (in some applications) which can be impacted by traffic; however, there may be support posts that may present a hazard if not properly designed, located and/or shielded. Such details require careful consideration in devising the test layout and matrix. Crash cushions may be positioned where they can be struck from opposing direction traffic; in such cases, deflector hardware or fender panels must be reversed on the opposite side for the test installation even though the installation may not be tested on the opposite side. Also, potential sites for a cushion may be sensitive to debris (i.e., elevated gore), whereas at other sites (i.e., roadside fixed object) the scattering of debris is a minimum hazard to other traffic. These factors should be considered in devising the test article layout.

TEST VEHICLE

Features

Vehicle design and its condition at the time of test can have major influence on the dynamic performance of an appurtenance. Among the more important parameters are vehicle bumper height, configuration, and stiffness; vehicle mass distribution and suspension system; and vehicle structure. For these reasons, the test vehicles should correspond closely to the recommended vehicle properties.

Condition

The test vehicle should be in sound structural shape without major sheet metal damage. Use of a vehicle for more than one crash test without repairs should be avoided, because vehicle damage in an initial test may effect an artificial performance behavior in later tests. This is particularly important in evaluating appurtenances such as a breakaway support, where vehicle crush significantly affects the fracture mechanism.

Types

Three passenger sedans and five heavy vehicles are shown in Table 2. Two of the passenger sedans, 2250S and 4500S, have been used for several years in appurtenance testing and the safety performance of a large number of operational devices is referenced to these vehicles. Because of the trend to smaller passenger vehicles and an increasing awareness for the need to provide better protection for heavy vehicles, the standard vehicle types have been expanded to include a new mini-compact car, designated 1800S, three sizes of buses, and two types of articulated cargo trucks. Generally, these vehicles are representative of current highway traffic and that which is anticipated in the 1980's. On the other hand, recent reviews of data on accidents and vehicle sales suggest that other vehicles such as pickups or passenger vans may need to be considered as future test vehicles. Several testing agencies have gained some experience with the additional types of vehicles in evaluating new and existing appurtenance hardware. The extension of vehicle size range to both smaller and larger vehicles will, of course, result in exceeding the capabilities of a large percentage of current hardware. Moreover, there is some concern that new appurtenance hardware that is needed to perform acceptably with the full range of vehicles (i.e., 1800S to 80,000P) may be neither technically sound nor economically prudent for most applications with the exception of breakaway or yielding supports. Nevertheless, when highway agencies investigate performance of new or existing hardware beyond the minimum matrix of test conditions (Table 3), it is recommended that the vehicles be selected from Table 2.

Test Vehicle Properties

In the previously used test procedures *(1)*, vehicle test mass and inertial properties were broadly defined as those of the composite vehicle and ballast, irrespective of the method of ballast attachment to the vehicle. In the new procedures, the importance of ballast restraint and ballast shifting on barrier performance is recognized.

Passengers in vehicles impacting breakaway supports move almost independently of the vehicle during the early stage of the impact (i.e., 0 to 50 ms) *(9)*, and, therefore, the vehicle velocity change during this initial stage is a function of only the vehicle test inertial mass and not the total vehicle and occupant mass (gross static mass). This is also true for the restrained driver coupled with short duration impacts that are characteristic of breakaway structures. With the 1800S sedan, nonspecific accounting for a dummy mass could introduce more than an 8 percent discrepancy in the procedures. Further, the more realistic choice of inclusion of an occupant surrogate in the 1800S vehicle may influence likelihood of rollover in certain tests.

Ballast for heavy vehicles that is free to shift or that can break loose during initial redirection collision is only partially effective in initial barrier loading because it tends to move independently of the vehicle. When the shifting ballast is contained within the vehicle structure (e.g., simulated occupants in a bus or cargo in a van truck), the ballast can have a major effect on the vehicle rollover stability and on the intensity of the second impact (e.g., tail slap). For cases where the shifting ballast is not contained within the vehicle structure, the effect of the ballast on barrier loading (both initial and secondary impact) and vehicle stability may be minimal.

Supporting research to fully define the importance of partially restrained or nonsecured ballast is not available. However, until such studies are performed, the testing procedures should be based on the conservative assumption that ballast restraint condition is important. Accordingly, the general approach in vehicle mass properties is the following:

Vehicle test mass, or test inertial mass, and mass moments of inertia will pertain to the vehicle mass and only that part of on-board test equipment and ballast that is rigidly secured to the vehicle throughout the collision. Gross static mass will consist of the inertial mass and that portion of test equipment, dummies, and ballast that is not rigidly secured.

This implies that mass of dummies, regardless of restraint condition, is not included in the vehicle inertial mass.

The shifting of ballast in a large vehicle may (1) decrease the impulse of the initial collision, (2) increase the impulse of the second collision (which may be greater than the initial collision), and/or (3) increase the probability of vehicle rollover. Ballast that shifts during initial collision should be representative of typical cargo or passenger loading, as appropriate, and should be reported separately from the vehicle inertial properties.

The inertial mass for the 1800S vehicle was determined by the following rationale. In 1986, the projected fifth percentile domestic passenger vehicle model will have a curb mass of 1790 lb (811 kg) *(10)*. Further, sales of mini-sized and subcompact cars are projected to be 30 percent of the car market in 1985. Recent sale trends suggest that such a market penetration of small car sales may have already been exceeded. Downsizing of vehicles is continuing in order to meet legislated fleetwide fuel economy mandates. Using the 1979 Honda CCCV Civic as a model, about 130 lb (59 kg) of components and fluids can be removed from the curb mass of 1790 lb (812 kg); items that can be removed include the rear seat—28 lb (13 kg), spare tire and rim—22 lb (10 kg), battery—30 lb (14 kg), and 50 lb (23 kg) of fuel. With the specified 1800 ± 50-lb (816 ± 23-kg) test inertial mass, the test instrumentation, on-board cameras, cine reference system and ballast, all rigidly secured to the vehicle, can have a mass that ranges from 0 up to 190 lb (86 kg).

Vehicle mass properties and geometry are to be determined for both the curb and test inertial mass conditions; these items are shown in Figures 1 and 2 for the passenger sedan and intercity bus, respectively. Similar data should be determined for the utility bus and tractor-trailer and reported.

Not all vehicle mass and mass moments of inertia properties are required for each test. For the passenger sedan tests, a testing agency may determine representative values for the vehicle type and use these values for subsequent tests as long as the vehicle model and test preparations are essentially unchanged. Moreover, mass moment of inertia values are generally not required for direct-on hits with the exception of off-center nose or bumper hits where the vehicle may spin out.

For large vehicle properties, mass moments of inertia may be theoretically estimated, although experimentally derived values would be preferred.

For input to computer simulations and for special tests, such as when the vehicle will interact with a curb or dike, it may be desirable to provide a more comprehensive description of the vehicle properties, such as wheel spring constants.

Guidance

A number of systems have been used by testing agencies in guiding the unmanned vehicle; these include (1) telemetry/steering wheel control, (2) channel guiderail for vehicle wheels, (3) cable and guide bracket mounted on the vehicle front wheel, and (4) steering linkage guide shoe set on center guiderail. Although the forces introduced by the guidance system are small compared to the appurtenance impact forces, the vehicle guidance should be terminated prior to impact.

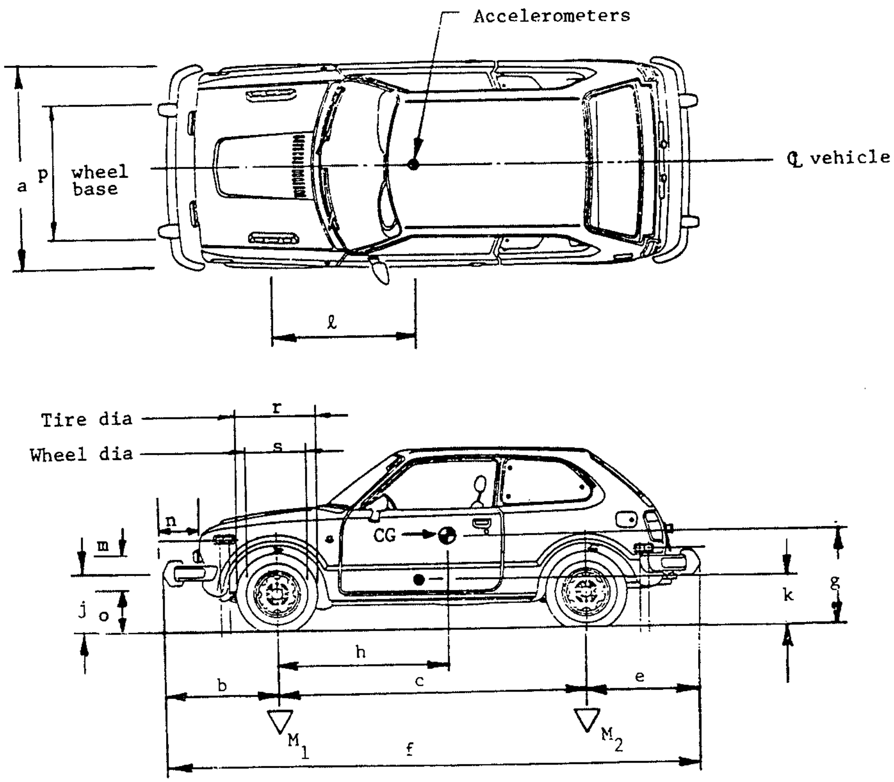
Brake Application

Because vehicle front wheels sometimes are detached during impacts, especially with longitudinal barriers, remotely actuated brakes are generally applied to the rear wheels only. This braking mode may cause instability (i.e., spin) of the car during after-collision trajectory. For this reason, braking should be delayed as long as safely feasible so that the unbraked after-collision trajectory can be observed. One suggestion is to use diagonal wheels, the front wheel away from impact and the impact-side rear wheel, for braking in order to reduce vehicle spin. This practice would also be representative of brake designs on many automobiles. In any case, vehicle position at the time of brake application should be noted in the report.

TEST CONDITIONS

Practical Limitations

Errant vehicles of all classes and mass leave the pavement and strike highway appurtenances with a wide range of speeds,



Geometry - in. (in.)

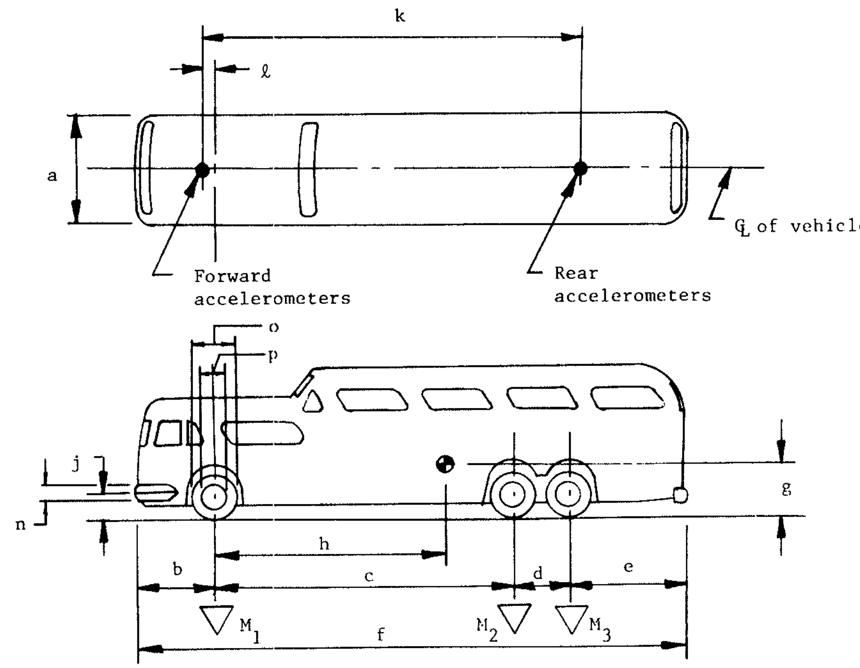
a	____	d	____	j	____	m	____	p	____
b	____	e	____	k	____	n	____	r	____
c	____	f	____	ℓ	____	o	____	s	____

Mass - lb (kg)	Curb	Test Inertial*	Gross Static**
M_1	____	____	____
M_2	____	____	____
M_T	____	____	____
h - in. (m)	____	____	____
g - in. (m)	____	____	____

Moments of Inertia (lb-ft-sec^2)	Test Inertial*	Gross Static**
Roll	____	____
Yaw	____	____
Pitch	____	____

*Ready for test but excludes passenger/cargo payload
**Gross ready for test including passenger/cargo payload

Figure 1. Passenger sedan properties.



Geometry - in. (m)

a	____	d	____	j	____	n	____
b	____	e	____	k	____	o	____
c	____	f	____	ℓ	____	p	____

Mass - lb (kg)	Curb	Test Inertial*	Gross Static**
M_1	____	____	____
M_2	____	____	____
M_3	____	____	____
M_T	____	____	____
h - in. (m)	____	____	____
g - in. (m)	____	____	____

Moments of Inertia* - lb-ft s^2	Test Inertial*	Gross Static**
Roll	____	____
Yaw	____	____
Pitch	____	____

* Ready for test but excludes passenger/cargo payload
**Gross ready for test including passenger/cargo payload

Figure 2. Large vehicle properties.

angles, and attitudes. It is a goal of highway engineers to design appurtenances that will satisfactorily perform for this range of impact conditions. Combinations of vehicle speed, mass, and approach angle that occur are unlimited. But the impact conditions must be reduced to a finite number in order to keep an evaluation test series within economic and practical bounds. The approach used in formulating the recommended test conditions is to evaluate the devices for cases that are very severe, yet practical. Accordingly, there is no assurance that an appurtenance will perform acceptably with other vehicle types presently in service or those vehicle types that may come into use during the normal service life of the device. Moreover, testing at the historical 60-mph (97-kph) speed instead of the recently established 55-mph (89-kph) maximum speed limit is to provide additional conservatism to the appurtenance evaluation. Further, this recommendation is consistent with current traffic speed data. In addition to examining appurtenances for a range of impacts, the low-speed (i.e., 20-mph or 32-kph) tests are important, because they explore the activation of the device at relatively low kinetic energy levels.

Whereas vehicles leave the pavement and impact barriers at nearly all angles, most reported collisions with longitudinal barriers occur at less than 25 deg with the majority less than 15 deg. Historically, the 25-deg approach angle has been accepted as a practical worst case and the 15-deg approach angle as a more typical collision condition.

A number of serious accidents have occurred when errant vehicles have skidded sideways into an appurtenance, such as a pole that fails to break away. Because of lack of crashworthiness of many current vehicles in the side direction, considerable intrusion of the passenger compartment occurs and results in an unusually high degree of hazard to the occupants. It appears that the typical vehicle side structure is less stiff than the front structure and cannot develop a sufficient force level to activate the appurtenance breakaway mechanism. This problem is recognized, but at this time there are no recommendations for standardized vehicle side impact tests for appurtenances. Work contemplated or underway by the NHTSA *(11)* and the FHWA *(37)* may lead to recommendations for such test procedures.

Test Matrices

Two test matrices are given in Tables 3 and 4. In Table 3, a minimum matrix of crash test conditions is presented for each type of roadside appurtenance. Supplementary tests are presented in Table 4 to further evaluate roadside appurtenances for special traffic conditions.

The crash test conditions given in Table 3 are similar to the minimum matrix presented in *TRC No. 191 (1)* with the major exceptions of six new tests with the 1800S type vehicle and the impact speed for Tests 43 and 51 being changed from 30 to 60 mph (48 to 97 kph). With regard to the 1800S type vehicle, evaluation criteria applied to these tests shall be the same as those applied to corresponding tests involving the 2250S vehicle; however, at the time of writing this report, there is no assurance that practical designs are in existence or can be developed that will fully meet the recommended performance criteria for all of the listed tests. Nonetheless, the expected importance of this class of vehicle in the traffic stream in future years is such that this size of vehicle must be considered in making decisions concerning roadside safety hardware. For the interim, tests with both the 1800S and 2250S vehicles are recommended as given in Table 3. However, if the test article fully meets recommended performance criteria with the 1800S vehicle, it may be assumed to meet recommended performance criteria with the 2250S vehicle; thus the 2250S tests may not be required. Depending on the results of future tests, it may be necessary to make decisions to accept certain hardware which does not fully meet the recommended appurtenance criteria for the 1800S vehicle but is otherwise acceptable. As further experience is gained with the 1800S vehicle, it is expected that the need for such decisions will be reduced and that changes in the recommended minimum matrix, such as deletion of certain 2250S vehicle tests, will be both practical and consistent with the philosophy of utilizing test procedures designed to provide a measure of safety performance for a broad range of vehicles in the traffic stream.

Supplementary test conditions given in Table 4 are generally new, although several have been used in research experiments for several years. The primary purposes of Test S13 are to investigate potential snagging of small wheels on beam and post systems and after-collision stability of the vehicle for longitudinal barriers in general. Also included are new structural adequacy tests for the multiple service level (MSL) approach *(6)* to longitudinal barrier design and selection, special tests to evaluate heavy vehicle stability during redirection, tests to evaluate special requirements for cargo and debris as well as heavy vehicle containment and a test that examines a possible critical gap in the minimum matrix (Table 3). The MSL approach is based on the premise that longitudinal barriers are subject to different ranges of collision severity depending on site geometrics and traffic characteristics. For example, the potential for a large number of severe collisions with a bridge rail on a highway with low traffic volume is practically nil; in contrast, one can reasonably expect a large number of severe collisions with a longitudinal barrier on highways with large traffic volume, especially when the traffic flow contains a high percentage of heavy vehicles. Since as a general rule for any given selected design type, longitudinal barrier costs increase in proportion to the severity of the design vehicle impact conditions, the purpose of the MSL approach is to tailor the roadside installation to more closely match specific site condition requirements. Three multiple service levels (MSL) are recommended for evaluating structural adequacy of a longitudinal barrier and its components. MSL 2 is the standard 4500S vehicle/60 mph (97 kph)/25 deg test used in the minimum matrix (Table 3) for Tests 10, 30, and 40. A less severe collision is designated for MSL 1, and three new tests are shown in Table 4: S14, S31, and S46. The most severe structural adequacy test is denoted by MSL 3 and specifies the 40,000P vehicle at 60 mph (97 kph) and 15 deg and is specified for Tests S15, S32, and S47. Test S19 is a structural adequacy test that is between MSL 2 and MSL 3 in collision severity. Three new tests in the procedures are S16, S17, and S18; the purpose of these tests is to evaluate the capability of the longitudinal barrier in keeping certain heavy vehicles upright during collision. Tests S20 and S21 are designed to evaluate the capability of a barrier to contain the vehicle, cargo, and any other debris on the traffic side of the barrier. Test S64 is recommended to examine the dynamic performance of a breakaway or yielding support for conditions intermediate to those denoted in the minimum matrix.

It is stressed that test conditions given in Tables 3 and 4 are not all-inclusive. There are other conditions that may need to be examined due to the peculiarity of the test article or unique feature of potential installation sites. The engineer is encouraged to carefully examine the test articles for vulnerable details and to devise additional test conditions to explore these.

Objectives of Test Conditions

Test conditions for each appurtenance have been established to evaluate one or more dynamic performance factors. The principal intent of tests given in Tables 3 and 4 is discussed in the following.

Longitudinal Barrier (Length-Of-Need)

Test 10 (4500S/60 mph/25 deg)

This test is considered primarily a strength test of the installation in preventing the vehicle from penetrating or vaulting over the system. The vehicle should be smoothly redirected without exhibiting any tendency to snag on posts or other elements or to pocket. Moreover, the vehicle should remain upright throughout the collision, and its after-collision trajectory should not present undue hazard to the vehicle occupants or to other traffic. Although occupant risk evaluation is a secondary factor for this test, vehicle dynamics and kinematics should be measured and reported.

Test S13 (1800S/60 mph/20 deg)

The objective of this test is to investigate the dynamic interactions of the small car with redirective barriers. Because the 1800S vehicle has small diameter wheels, generally with the forward wheels being driven, there is concern that a forward wheel will wedge under the lower beam of a beam and post system and snag on a post *(38)*. Further, there is concern for vehicle rollover during or after collisions with typical shaped barriers due to critical inertial properties of this vehicle *(39)*. Goals for this test are (1) that the vehicle should be smoothly redirected without exhibiting any tendency to snag on post or other elements or to pocket, (2) that the vehicle should remain upright throughout the collision, and (3) its after-collision trajectory should not present undue hazard to other traffic.

In the past, all longitudinal barriers were evaluated for the single set of strength conditions denoted by Test 10 irrespective of their ultimate application. Two other strength or multiple service level tests are given in Table 4 that may be used in lieu of, or in addition to, Test 10.

Test S14 (4500S/60 mph/15 deg)

This test evaluates a longitudinal length-of-need section for MSL 1 condition. In general, such barriers are intended for highways with low traffic volume. As with Test 10, this is primarily a strength test, and the test article should perform to the same criteria as Test 10.

Test S15 (40,000 P/60 mph/15 deg)

This test evaluates a longitudinal length-of-need section for MSL 3 condition. Barriers developed to this strength are intended for highways with high traffic volume and a high percentage of heavy vehicles. This is primarily a strength test, and the test article should perform to the same criteria as Test 10.

Selection of the appropriate multiple service level is beyond the scope of this report; however, in the absence of such selection, the testing agency should continue the use of Test 10. Also at this time, it is not clear as to whether MSL 3 barriers might be proposed at potential sites where large angle impacts with 4500S vehicles might occur. This problem may be addressed by inclusion of Tests 10, 30, and 40 in the test matrix for MSL 3 longitudinal barriers.

Two additional tests are presented in the minimum matrix for the length-of-need section for evaluating occupant risk: 2250S and 1800S vehicles at 60 mph (97 kph) and 15 deg. Establishment of these conditions was based on the following factors: (1) With other factors being equal, the redirection of small cars impacting a system where stiffness is dependent on deformed shape alone will be more severe than for a large car. Also, the small cars have a shorter wheel base and a narrower track, making them more vulnerable to rollover during redirection. (2) The 60-mph (97-kph) and 15-deg impact represent an appropriately severe test for measuring redirection performance of the test article in terms of vehicle accelerations and vehicle damage. Hopefully, the vehicle should be in a condition after the test that would enable it to be driven from the collision site to a safe area.

Test 11 (2250S/60 mph/15 deg)

The prime purpose of this test is to assess the potential risk or hazard to vehicle occupants during collision with the test article. However, the vehicle must remain upright and be smoothly redirected. For example, the 2250S vehicle has in some tests snagged or pocketed with abrupt accelerations or spinouts, or the vehicle has rolled over after colliding with certain concrete safety shapes. For vehicles remaining upright and smoothly redirected, occupant risks are projected based on vehicle accelerations and calculated kinematics of occupants within the compartment space.

Test 12 (1800S/60 mph/15 deg)

This is a new occupant risk test involving the 1800S vehicle. It is a goal for this test to eventually replace Test 11. However, at this time there is no assurance that existing appurtenance or new practical concepts will fully meet all performance requirements. In the interim until sufficient crash test experience is gained with the 1800S vehicle, test articles fully meeting performance requirements of Test 11 should be considered acceptable irrespective of Test 12 results. In the event that Test 12 is performed prior to Test 11 and the test article performance is judged to fully meet the performance requirements, then the testing agency may assume Test 11 conditions are met without performing the second occupant risk test.

Three supplementary tests (i.e., S16, S17, and S18) are given in Table 4 to evaluate the capability of the length-of-need section in keeping a heavy vehicle upright during redirection. Keeping all vehicles upright during all crash tests is a worthy goal as occupant risks are generally more severe and less predictable in a vehicle rollover. There are selected sites where the number of heavy vehicles, including utility buses such as those used to transport school children, farm workers, etc., is significant, and the possible added cost of a barrier to keep the redirected vehicle upright at these sites is considered acceptable. For the stability tests, the 20,000P utility bus is specified as (1) it represents an important percentage of heavy vehicles; (2) it has a relatively high center-of-mass, thereby making it susceptible for being upset during redirection; (3) the arrangement of passenger surrogates in a standard condition is readily achieved; and (4) the effects of shifting passenger mass during redirection is believed to increase the rollover potential and make the test more critical. It is noted that the utility bus structure has been found to exhibit failures during 60-mph (97-kph) and 15-deg impacts; these failures have obscured the barrier evaluation. In particular, the front suspension/vehicle frame connection has failed in at least two tests which permitted considerable unsymmetrical rearward displacement of the front wheel assembly. This failure in itself was judged sufficient to cause the vehicle to roll over. Thus, the tests were more an evaluation of the vehicle crashworthiness rather than a demonstration of the barrier capabilities.

Two evaluation factors are applied to the three stability tests: (1) vehicle containment and (2) whether the bus remains upright or rolls over during redirection.

Test S16 (20,000P/45 mph/7 deg)

The impact severity of this test is approximately one-half the MSL 1 strength test (Test S14); this test is considered appropriate for test articles developed to the MSL 1 requirements. One test at these conditions has been conducted to date on a MSL 1 bridge rail with acceptable results.

Test S17 (20,000P/50 mph/15 deg)

The impact severity of this test is about 50 percent greater than the MSL 1 strength test (Test S14); this test is considered appropriate for test articles developed to the MSL 2 requirements. No tests have been performed to date with these conditions; thus the relative ease or difficulty in meeting these conditions is unknown. It should be noted that the weight-horsepower ratio and slow acceleration of these vehicles make travel at 60 mph (97 kph) difficult, and for the most part, the routes utilized by this type of vehicle together with the stop-and-go nature of their mission precludes a significant amount of travel at speeds in excess of 50 mph (80 kph).

Test S18 (20,000P/60 mph/15 deg)

The impact severity of this test is slightly in excess of the MSL 2 strength test (Test S15); this test is considered appropriate for test articles developed to the MSL 3 requirements. As discussed earlier, a number of tests conducted with these conditions have resulted in vehicle failures that have obscured the test article performance.

Another special requirement for length-of-need sections of some longitudinal barriers is to contain all cargo and debris as well as the vehicle on the traffic side of the barrier. Such a barrier may be required at special sites where the trajectory of cargo and/or debris over the barrier could present undue hazard to nearby traffic, pedestrians, or facilities. For example, bridges that span busy parks, schools, industrial plants, or heavily traveled highways may require a high level of assurance that the cargo of heavy vehicles will be contained on the bridge along with the redirected vehicle. Thus, a heavily loaded tractor-trailer is selected as a critical vehicle to redirect along with its cargo. Evaluation criteria are whether or not the vehicle and cargo is contained on the traffic side of the longitudinal barrier.

Test S20 (80,000A/50 mph/15 deg)

This is a new test that has not been performed to date. The vehicle is a tractor-trailer with a mass of 80,000 lb (36,000 kg). The tractor is unspecified, although cab-over-engine design is preferred. The trailer is to be a van type, and the ballast is to be bagged sand uniformly stacked within the van without tie-downs. Although it is preferred that the tractor and trailer remain upright during redirection, the articulated vehicle is known to be unstable during and after such a collision. The testing agency should extensively measure pretest vehicle properties and report them in a format similar to that shown in Figure 2.

Test S21 (80,000F/50 mph/15 deg)

This is a new test that has not been performed to date. With exception of the fluid tanker trailer, discussion presented in Test S19 applies. The trailer should have a 8000-gal (30,000-liter) capacity filled with water.

Because of the articulated nature of the vehicle, it is believed that test conditions specified by S20 and S21 are less severe with regard to longitudinal barrier loading than the MSL 3 strength test. This is due in part to the staged redirection of the vehicle; the tractor is redirected and then the trailer is redirected. However, this will not be known until sufficient crash test experience is gained with S20 and S21.

Longitudinal Barriers (Transitions)

Transitions of concern generally occur between longitudinal barriers with different lateral flexibility. Transitions may occur between (1) two barrier systems with the same multiple service level, (2) two barrier systems of different multiple service level, or (3) two different types of longitudinal barriers such as guardrail to bridge rail. Because the transition normally will be situated in a length-of-need, it should be evaluated according to the length-of-need strength test according to the higher service level regardless of the service level order in the transition. The principal failure mode is for the vehicle to pocket or snag, with this generally occurring at transitions from flexible to rigid systems. Transitions from rigid to flexible systems are normally not so critical. A careful examination of system plans is recommended to determine whether safety performance questions are associated with flexible-rigid connections such as structural adequacy of the connection or potentially hostile geometric discontinuities. When such questions are revealed, they should always be investigated.

Test 30 (4500S/60 mph/25 deg)

The minimum matrix strength test is similar to the length-of-need strength test. The impact point is specified at 15 ft (4.5 m) upstream from the second and more laterally stiff system. In the event of multiple service level requirements, Test 30 is considered MSL 2 and should be used when one system is categorized as MSL 2 and the other is either MSL 1 or 2.

Test S31 (4500S/60 mph/15 deg)

This test should be used instead of Test 30 when both of the barrier systems are categorized as MSL 1.

Test S32 (40,000P/60 mph/15 deg)

This test should be used in addition to Test 30 when at least one of the barrier systems is categorized as MSL 3.

Longitudinal Barrier (Terminals)

Terminals are evaluated for (1) adequacy of the anchorage at the beginning of the length-of-need (Tests 40, S46, S47), (2) end-on hits for three sizes of cars (Tests 41, 43, and 45), and (3) redirective performance midway between the nose and the beginning of the length-of-need (Tests 42 and 44).

Test 40 (4500S/60 mph/25 deg)

This test is to evaluate the adequacy of the terminal anchorage of an MSL 2 or any unspecified downstream longitudinal barrier. It is to be noted that the point of impact is specified as being at the beginning of the length-of-need; this point may fall within the terminal configuration and not necessarily at the beginning of the typical longitudinal barrier segment. This impact point should be selected at the minimum distance from the terminal nose where full anchorage and redirective performance is achieved in order to minimize lengths of in-service installations, thereby reducing installation costs and length of roadside hazards. The vehicle should be smoothly redirected without exhibiting tendency to pocket or snag.

Test S46 (4500P/60 mph/15 deg)

For the case where the downstream longitudinal barrier system is MSL 1, then Test S46 should be performed instead of Test 40. Otherwise, procedures and performance requirements for Test 40 apply to this test.

Test S47 (40,000P/60 mph/15 deg)

For the case where the downstream longitudinal barrier system is MSL 3, then Test S47 should be used in addition to Test 40. Otherwise, procedures and performance requirements shown for Test 40 apply to this test.

For the end-on hit, it is assumed that the terminal may perform as either a crash cushion, in which case the vehicle is brought to a controlled stop, or a deflective device that directs the vehicle back to the pavement or to a path behind the installation. In either instance, the device should be examined for the three vehicle sizes. In the case that soil strength is important in the development of the anchorage force and the breakaway post, the weak soil described in Table 1 should be used.

Test 41 (4500S/60 mph/0 deg)

The objective of this test is to evaluate the energy-absorbing/dissipation or redirective properties of the test article for a severe set of impact conditions. Vehicle stability, occupant risk, and after-collision trajectory are chief evaluation factors.

Test 43 (2250S/60 mph/0 deg)

The primary purpose of this test is to demonstrate that vehicle decelerations and, hence, occupant risks are within acceptable limits. Vehicle stability and after-collision trajectory are also important factors. This test is sufficient for those devices that produce fairly constant or slowly varying vehicle decelerations. On the other hand, an additional test is recommended for staged devices—those devices that produce a sequence of individual vehicle deceleration pulses (i.e., lumpy devices) and/or those devices comprised of massive components that are displaced during dynamic performance. The lower speed test, 20 (32) instead of 60 mph (97 kph), is considered critical because of the relatively high initiation force required to activate or mobilize such terminals—such as terminals consisting of breakaway devices.

Test 45 (1800S/60 mph/0 deg)

This is a new test; there is no assurance that existing terminal or newly developed concepts will fully meet objectives of vehicle stability, occupant risk and after-collision trajectory, and still continue to meet requirements of other terminal tests. At the time of this writing, it is considered necessary for terminals to perform acceptably for Test 43; it is preferred that the terminal also perform acceptably for Test 45. Test 45 is considered more demanding than Test 43; hence, test articles fully meeting objectives of Test 45 are not required to be evaluated by Test 43. As with Test 43, the additional low-speed test may also be required.

The behavior of vehicles striking within the terminal is evaluated by Tests 42 and 44. Acceptable performance is by either redirection or controlled penetration by the vehicle. Also, vehicle stability and occupant risk are important factors.

Test 42 (2250S/60 mph/15 deg)

Impact point for this test is midway between the nose and the beginning of the length-of-need. From previous tests, the critical problems have been that the vehicle is either snagged or is upset as it penetrates or vaults over the test device.

Test 44 (1800S/60 mph/15 deg)

This test is similar to Test 42 with exception of the 1800S vehicle. This test is believed to be more demanding than Test 42 as the smaller car is more easily upset during collision. At this time, it is unknown whether existing terminals or new devices will fully meet requirements of this test. Test articles fully meeting requirements of Test 44 may be assumed to meet those for Test 42.

Crash Cushions

The test matrix is formulated to evaluate devices such as clusters of sand drums or oil drums that will be used to shield elevated gores or bridge piers. Other velocity attenuation devices such as the "dragnet" or gravel bed are special cases, and the recommended crash cushion test matrix is not directly applicable.

Moreover, the test matrix is limited to passenger sedans and is not applicable to large vehicles. The reason for this is threefold: (1) although a crash cushion for heavy vehicles is desirable, under present technology the space and energy dissipation requirements for larger vehicles are excessive for a large percentage of potential sites and, hence, a heavy vehicle crash cushion would not be practical; (2) tractor-trailers are dynamically unstable vehicles, prone to jackknifing, especially when subjected to intense acceleration forces associated with present type crash cushions and, thus, the performance of a crash cushion would be unpredictable for this type of heavy vehicle; and (3) accident statistics do not reveal a clearly defined need for a heavy vehicle crash cushion *(12)*. In the event that a crash cushion is developed for heavy vehicles, the recommended test matrix may be expanded to include the more severe impact conditions.

A crash cushion is expected to perform for a wide range of passenger sedan impact conditions. In addition to vehicle mass, speed, and angle of approach, the point of impact adds another dimension to the array of possible collision situations. Based on research experience and generally excellent accident experience with the first-generation crash cushion designs *(13)*, a minimum matrix of five tests has been devised that examine and demonstrate a device at five critical combinations of impact conditions. Because future generation crash cushions may depart radically from current designs, the future designs should be examined carefully for other critical combinations of impact conditions.

The test matrix evaluates a crash cushion for speeds to 60 mph (97 kph) and these devices are generally applicable to all classes of highways. For lower speed highways, it may be appropriate to design special crash cushions for lower impact velocities. It is recommended that these lower impact velocity crash cushions be evaluated at 5 to 10 mph (8 to 16 kph) above the posted or operational speed limit for the five tests instead of 60 mph (97 kph). For crash cushions mounted on maintenance trucks, see discussion earlier in this chapter under "Vehicle Crash Testing" (subsection "Permanent or Temporary Appurtenances").

Test 50 (4500S/60 mph/0 deg)

The objective of this test is to evaluate the energy-absorbing/dissipation capacity of the test article for a severe set of impact conditions. Occupant risk is the chief concern.

Test 51 (2250S/60 mph/0 deg)

The primary purpose of this test is to demonstrate that occupant risk, which is generally critical for the smaller cars, is within acceptable limits. This test is sufficient for those devices that produce fairly constant or slowly varying vehicle decelerations. On the other hand, an additional test is recommended for staged devices—those devices that produce a sequence of individual vehicle deceleration pulses (i.e., "lumpy" devices) and/or those devices comprised of massive components that are displaced during dynamic performance. The lower speed test, 20 (32) instead of 60 mph (97 kph), is considered more critical because of the relatively high initiation force required to mobilize such crash cushions—such as cushions consisting of individual fragmenting structures.

Test 52 (1800S/60 mph/0 deg)

This is a new test; there is no assurance that existing crash cushions will fully meet objectives of vehicle stability, occupant risk, and after-collision trajectory. Presently, it is considered necessary for the crash cushion to perform acceptably with Test 51; it is preferred that the crash cushion also perform acceptably for Test 52. Test 52 is considered more demanding than Test 51; hence, test articles fully meeting objectives of Test 52 are not required to be evaluated by Test 51. As with Test 51, the additional low-speed test may be required.

Test 53 (4500S/60 mph/20 deg)

This test is to evaluate crash cushions for redirectional performance capability. It is desirable to have crash cushions that will perform at highway speed and a 25-deg angle; however, most of the present-generation devices lack this capability. Hence, until this capability is developed, the 20-deg impact angle is considered as appropriate test criterion where redirectional performance is evaluated. The point of impact should be approximately at mid-length along the crash cushion side but not more than 20 ft (6.0 m) upstream from the backup structure to assure that the vehicle is smoothly redirected and is not pocketed or snagged at the crash cushion-backup structure connection; the backup structure should simulate a bridge rail end.

For crash cushions that do not redirect vehicles when struck on the side of the device such as for the Energite/Fibco/sand tire crash cushions, Test 53 is modified as follows: the vehicle shall be 4500 lb (2040 kg), test speed of 60 mph (97 kph), an impact angle of 15 deg with the line of symmetry of the device, and the center of the vehicle should be aligned on the corner of the test hazard. It is important that the speed of the vehicle at contact with the shielded rigid object be reported in this test. The average acceleration of the vehicle after impact with the shielded rigid object should also be reported. It is recognized that the selected impact angle and point of impact represent a severe set of test conditions. Field data indicate that such collisions occur rarely with these devices *(13)*. However, the data from this test are an important reference for comparing transition zone designs.

Test 54 (4500S/60 mph/10-15 deg)

This test evaluates the test article for unsymmetrical loading at the nose. Stability of the vehicle with respect to spinout, rollover, and pocketing is the primary concern of this test. Analysis of accident reports reveals that these test conditions occur frequently. Whereas Tests 50, 51, and 53 have been used in developing first-generation crash cushions, Test 54 was later added and provides the highway engineer with insight into the crash cushion performance. The test engineer shall establish the exact test conditions within the specified limits so that test article failure is most likely to occur.

Breakaway or Yielding Supports

Four tests are recommended in Table 3 for this type of appurtenance: a high and low speed test with the 2250S vehicle and a high and low speed test with the 1800S vehicle. Objective of the low-speed [i.e., 20 mph (32 kph)] tests is to evaluate the breakaway or activation mechanism of the device and the high-speed [60 mph (97 kph)] tests is concerned with vehicle stability and trajectory; occupant risk and test object penetration into the passenger compartment space are important to all tests.

Test 60 (2250S/20 mph)

The impact point should be centered on the vehicle bumper; generally this point is the most flexible area of the bumper and will be critical for test devices that rely on rapid buildup of force to activate. A new provision of this test is that the vehicle mass is specified as the inertial mass and loose ballast or dummies, regardless of restraint, will be ignored if previously used momentum change procedures are used.

Test 62 (1800S/20 mph)

This is a new test but is similar to Test 60 with exception of vehicle size. Test 62 is more stringent than Test 60; accordingly, no assurance can be given that breakaway or yielding supports qualified for Test 60 will meet the smaller car test. On the other hand, test articles meeting requirements for Test 62 may be considered to satisfy requirements of Test 60.

Research is underway to develop a pendulum or bogie vehicle test equivalent for Test 62.

Test 61 (2250S/60 mph)

The impact point for Test 61 as well as Test 63 should be at the quarter point of the bumper. In addition to occupant risk during collision, the vehicle stability after the collision is important. A single dummy is recommended for this test and should be placed in the front seat on the opposite side of the centerline from the device impact point; preferably the dummy should be in the driver position.

Test 63 (1800S/60 mph)

This is a new test but is similar to Test 61 with exception of vehicle size. Test 63 is more stringent than Test 61; accordingly, no assurance can be given that a test device qualified for Test 61 will meet the smaller car test. On the other hand, test articles meeting requirements for Test 63 may be considered to satisfy requirements of Test 61.

Test S64 (1800S/40 mph)

For yielding and basebending supports, the failure mechanism of the support during impact may differ as a function of impact speed and no assurance can be given that some intermediate speed may produce a higher change in vehicle velocity. For this reason, Test S64, shown in Table 4, evaluates the breakaway support at 40 mph (64 kph).

DATA ACQUISITION SYSTEMS

Specifications Purpose

Dynamic performance of a highway appurtenance ultimately is judged by the degree of hazard to which the vehicle occupants are subjected during impact and to which other traffic is subjected as a result of the redirected vehicle. Hence, data acquisition systems are specified to document the dynamics and kinematics of the vehicle and test article immediately before, during, and immediately after impact.

Tolerance Specifications

The limits of measurement tolerances given in Table 5 were established based on the following factors: the minimum variation in the parameters of current or near-future significance, and economical and technical feasibility. Tolerances are presented in terms of absolute values, rather than the percentage of full scale, to promote proper selection of equipment. For instance, a 1 percent tolerance would permit a variation of 5 g's for a 500-g accelerometer that is selected primarily for its dynamic overrange and shock protection while ignoring the important signal/noise ratio; the 500-g accelerometer would be a poor choice since the 5-g variation could obscure significant vehicle response, which generally ranges below 15 g.

Broadband Recording

It is recommended that signals from the vehicle accelerometers be recorded in broadband (i.e., 0-min 500 Hz) on magnetic tape as a permanent record, although the data may be subsequently filtered according to SAE J211b Channel Class 180 *(14)* for reporting. Hence, the broadband data may be filtered to other channel class requirements to meet future needs. Data from dummies should be recorded in accord with SAE J211b Class 1000. Equipment and procedures used in subsequently processing the data should be evaluated to assure that frequency band width and amplitudes are not degraded below the appropriate channel classes.

Accelerometer Calibration

The complete accelerometer data acquisition system should be calibrated against a known standard as suggested in SAE J211b *(14)*. For example, the transducer should be physically exercised through the acceleration and frequency envelope and the signal conditioned and recorded through the acquisition system; deviation from the standard should be calculated for the envelope. Just prior to test, the acquisition system should be calibrated for at least one set of known conditions (i.e., acceleration intensity and frequency) by physically exercising the transducer; the recorded calibration signal will serve as a check for operation status of the complete system and a scaling function for data processing. Another calibration technique is to artificially produce an accelerometer signal by introducing a precise voltage change in the circuit and recording the conditioned signal; however, this technique is less preferred because the transducer mechanical mechanism is left unchecked. After-test calibration of the complete accelerometer system is important and should be performed to ascertain operational status of the system and identify possible measurement problems.

Accelerometer Mounting

Mounting of accelerometers in the vehicle should be performed with care so as to minimize local effects and structural ringing. A metal block of 1 × 5 × 5 in. or larger is suggested for combining the accelerometers on a common structure; the block can then be attached to a vehicle frame or pan member. A more elaborate technique is to span between the passenger sedan "B" pillars with a rigid steel beam (i.e., 10 plf or greater) and then attach the accelerometer block to the beam. Care should be taken to assure that one set of accelerometers is located on the vehicle centerline at the longitudinal center of vehicle test inertial mass distribution because any vehicle roll, pitch, or yaw during the test will result in changes in the accelerometer signals as a function of accelerometer locations. Thus, unless front/rear vehicle mass distribution is measured before the test and an accelerometer set location positioned accordingly, the desired standardization for comparability of test results will not be achieved for such tests.

Sign Convention

The sign convention for vehicle positive accelerations is shown in Figure 3. Positive acceleration occurs when the vehicle center-of-mass increases in velocity in the forward, left, or upward directions with respect to the driver's attitude.

Optional Data

Although not required at this time, the testing agency is encouraged to develop capability to record the six basic accelerations of the vehicle: x, y, z, roll, pitch, and yaw. These data, as well as corresponding velocities and displacements, should be shown in the report in plots or tables as a function of time.

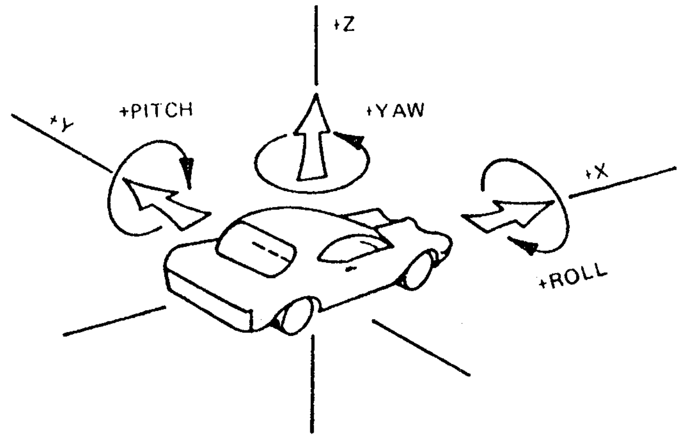


Figure 3. Vehicle accelerations sign convention.

High-Speed Cine

High-speed cine is essential for study of crash dynamics to determine the behavior of the test vehicle and roadside structure. In addition, high-speed cine has been used by several agencies as a backup system for determining vehicle accelerations and kinematics. Guidance for this secondary system would consist of (1) minimum film speed of 500 fps, (2) internal or external timing device, and (3) stationary references located in field of view of at least two cameras positioned 90-deg apart. Layout and coordinates of references, camera positions, and impact point should be reported. Two vehicle references should be located on the vehicle roof, one positioned directly above the vehicle center of mass and the second 5.0 ft (1.5 m) to the rear for the standard car and 4.0 ft (1.2 m) for the small car. Instant of impact should be denoted by a flash unit placed in view of data cameras. The instant of impact should also be recorded on magnetic tape or oscillograph.

Strain Gages

A discussion of the application of strain gages is beyond the scope of this document. A most complete presentation of strain gage technology has been compiled by Murray and Stein *(15)*. Calibration procedures on bonded strain gages are presented in ASTM E251-67 *(16)*.

Dummies

Two categories of dummies are available for use in vehicle crash tests. Anthropometric dummies are devices currently approved for vehicle occupant hazard assessment in FMVSS 208 *(17)* and FMVSS 214 *(11)*. These devices are instrumented with head and chest triaxial accelerometers and femur load cells. Anthropomorphic dummies are less specialized devices used to (1) simulate occupant mass and (2) exhibit occupant kinematics for on-board cameras.

A single dummy, either an anthropometric or anthropomorphic device, is recommended for all tests involving the 1800S type vehicle; the single dummy is also preferred for the 2250S vehicle tests. Placement and restraint conditions for dummies are discussed in this chapter under earlier section

"Test Vehicle," subsection "Test Vehicle Properties."

In no event should data from dummies be used as the sole basis for accepting or rejecting a design.

Vehicle Damage Scales

Both traffic accident data (TAD) scale and vehicle damage index (VDI) are specified for the following reasons. First, TAD has been in use for a number of years by various accident investigation agencies, and a considerable bank of data exist relating TAD to occupant injuries. Hence, by not reporting TAD, the tie of future tests with these historical data would be lost. And second, the National Highway Traffic Safety Administration (NHTSA) has standardized on the VDI for its multidisciplinary accident investigations. Therefore, VDI is needed to tie test vehicle damage (in which vehicle accelerations are measured) to real accidents in which occupant injury is documented.

PERFORMANCE EVALUATION

Relative Safety

In-service experience has indicated that vehicle collisions with even the best highway appurtenances have resulted in injuries and fatalities. Accordingly, placement of an appurtenance close to the traveled way should in general be avoided. However, the placement of an appurtenance may be justified by (1) relative severity, in which case the appurtenance (such as a longitudinal barrier or crash cushion) lessens the probability of occupant injuries and fatalities when compared to permitting the errant, ran-off-the-road vehicle access to an unshielded road side hazard *(18)*; or (2) the benefit of an appurtenance (such as lighting or signing) in reducing the number of injury and fatality accidents.

Screening and Comparison

The evaluation criteria presented in the recommended procedures are limited to appraising safety performance of highway appurtenances for idealized vehicle crash test conditions. As the purposes of the crash tests are to screen out those candidate systems with functional deficiencies and to compare the relative merits of two or more promising candidate appurtenances, the test results are insufficient to project the overall performance of an appurtenance for in-service use or in an actual collision situation. The final evaluation of an appurtenance must be based on carefully documented in-service use. The highway engineer may also give discretionary consideration to factors of cost and aesthetics in appraising the overall performance of an appurtenance; guidelines for these two factors are beyond the scope of this document.

Criteria for evaluating vehicle crash tests of an appurtenance consist of three interrelated factors: structural adequacy, occupant risk, and vehicle after-collision trajectory.

Structural Adequacy

This factor essentially assesses the appurtenance from a structural and mechanical aspect. Depending on the appurtenance, conditions to be examined include:

1. *Strength.* For longitudinal barriers, this requires the containment and redirection of the design vehicles. Terminals must develop necessary anchoring forces for anticipated site conditions. Unless otherwise designed, the appurtenance must remain intact so that detached elements and debris will not create hazards for vehicle occupants or other traffic.
2. *Geometry.* Longitudinal barrier rail members must engage the colliding vehicle at proper height to prevent the vehicle from wedging under or vaulting over the installation. The vehicle-barrier contact surface should facilitate a smooth redirection. Rail discontinuities such as splices and transitions and other appurtenance elements such as support posts must not snag or abruptly engage elements of the car such as a bumper, fender, or wheel. Shaped rigid barriers, such as the New Jersey concrete barrier, must be designed to consider the stability of design passenger sedans.
3. *Mechanisms.* Stiffness, deformation, yielding, fracture, energy absorptions/dissipation, etc., are characteristics of appurtenances that must be verified over the range of design vehicles.

In general, an appurtenance should perform its function of redirecting, containing, or permitting controlled penetration of the test vehicles in a predictable and safe manner. On the other hand, violent roll or rollover, pitching, or spinout of the vehicle reveal unstable and, hence, an unpredictable dynamic interaction that is an unacceptable performance feature of the test article.

Occupant Risk

The relationship between occupant safety and vehicle dynamics during interaction with a highway appurtenance is tenuous because it involves such important, but widely varying, factors as occupant physiology, size, seating position, attitude, and restraint, and vehicle interior geometry and padding. Although considerable effort has been devoted in recent years to exploring human tolerance to the crash environment, experimental conditions have been idealized to simple situations [(e.g., young males subjected to single half sine or square wave acceleration pulse while restrained with lap and shoulder belts *(19)*]. Although findings from these efforts serve as a benchmark, they are not directly applicable to the complex highway collision. From the mass of multidisciplinary accident investigation data that are being acquired, the general cause of the collision and the resulting occupant injuries are being determined; however, precise vehicle dynamics (such as acceleration histories during the impact) can only be approximated through current collision reconstruction computer model simulation techniques.

Occupant risk evaluation procedures have been extensively revised from those presented in *TRC 191 (1)*, although the acceptance levels of safety performance are judged to be approximately the same. The revised procedures, based on the occupant flail space approach, assess all classes of appurtenances according to the same reference *(9)*. The revised procedures will require some changes in the method of recording and processing experimental data.

Flail space approach. Two extreme cases of accident severity are when (1) an occupant is ejected or partially ejected and (2) when the occupant compartment space is penetrated or collapsed during a collision. The fact that these two cases did not occur in a full-scale crash test can be objectively evaluated by documenting that the vehicle remained upright, that the vehicle doors remained closed, and that the passenger compartment was not violated during the collision.

The third case, which is the more predominant appurtenance crash test situation, is when the occupant is propelled against the restraint system and/or one or more surfaces of the vehicle interior including the steering wheel. Although jerking motions such as whiplash can cause spinal injury, the principal injuries occur when the occupant strikes some part of the compartment interior. The extent of injury is dependent on (1) the occupant-to-compartment impact velocity, the occupant part and orientation in contact and the degree of padding and (2) the intensity of forces subjected to the occupant during the subsequent vehicle velocity change. Although there may be rebound from the occupant-compartment impact due to the elastic nature of the vehicle interior, for simplicity it is assumed the compartment deforms in a plastic manner and that no rebound occurs. Thus, the occupant remains in contact with the vehicle and decelerates with the same intensity as the vehicle. Accordingly, the appurtenance occupant risk assessment criteria are directed to the two distinct and sequential phases of collision:

1. After vehicle impact, the vehicle compartment surfaces accelerate toward the occupant as the occupant continues to move with the vehicle pre-impact velocity; the occupant impacts on the dash, windshield, or door. The occupant impact velocity, the critical parameter, is determined by assuming the occupant moves as a free body across the compartment space propelled by the vehicle collision accelerations.
2. After the occupant impact, the occupant remains in contact with the vehicle interior and experiences the same acceleration forces as the vehicle; vehicle maximum 10 ms average acceleration during this ridedown phase is the critical parameter.

In the flail space approach, only vehicle lateral and longitudinal and not vertical accelerations, measured at the vehicle center-of-mass, are used. By requiring that the vehicle in the occupant risk test remain upright throughout the collision, it is believed that the vertical component of vehicle acceleration becomes of secondary importance with regard to occupant kinematics for the level terrain tests described in this document and for most roadside appurtenances; consequently, the vertical acceleration is considered an optional factor at present and has been neglected in the flail space calculations. Moreover, the front seat occupants in both the 1800S and 2250S vehicle are very near and just aft of the vehicle center-of-mass; any moderate roll, pitch, and yaw motions of the vehicle will have only minor effect on the occupant kinematics and, hence, have been neglected in the current flail space approach.

The appurtenance performance design strategy would be to (1) keep the occupant-vehicle interior impact velocity low by minimizing average vehicle accelerations or vehicle velocity change during the time the occupant is traveling through the occupant space and (2) limit peak vehicle accelerations during occupant ridedown.

Threshold occupant impact velocity change, $(\Delta V)_{LIMIT}$, and occupant ridedown acceleration, $(a)_{LIMIT}$, have been derived from several sources including human volunteer testing, sled tests of animals, cadavers, and dummies, and automotive accident statistics. An attempt has been made to set the threshold values at a level equivalent to the American Association of Automotive Medicine Abbreviated Injury Scale (AIS) of 3 or less *(25)*. AIS-3 classifies the resulting injury as severe but not life threatening.

Occupant Velocity Change (Longitudinal). Based principally on dummy head impacts into windshields with V ranging from 44 *(20)* to 51 *(21)* fps (13.4 to 15.5 m/s) and with the resulting FMVSS 208 Head Injury Criteria less than 1000, a nominal 40 fps (12 m/s) appears to be a reasonable impact velocity threshold $[(\Delta V)_{LIMIT}]$ for unrestrained occupants striking the windshield or instrument panel. It is believed that the 40 fps (12 m/s) value is consistent with compartment design and padding of the preponderance of present vehicle population. Because the steering wheel reduces the flail space for the driver, the driver-steering wheel impact velocity will be less than that for the front seat passenger although the driver ridedown accelerations may be higher.

Occupant Velocity Change (Lateral). Most human tolerance data for lateral impact have been acquired from automobile accident data files. The human may exhibit similar longitudinal and lateral velocity change tolerances; however, this fact cannot be concluded from automobile accident data, probably because of compartment space intrusion that is typical of car-to-car and car-to-fixed-object collisions. Accident statistics from France *(22)* indicate that injuries of AIS 3 or greater were sustained in 50 percent of side impact cases for a ΔV of at least 31 fps (9.4 m). Where the compartment space is not intruded, an upper lateral occupant impact velocity of 30 fps (9.1 m/s) appears to be a reasonable limit that is consistent with FMVSS 214 Advance Notice proposal and with accident statistics from France. It is noted that compartment space intrusion rarely, if ever, occurs during vehicle redirectional crash tests. On the other hand, accident records reflect that side intrusion frequently occurs when the vehicle skids sideways into a rigid narrow fixed object or even into a "breakaway support." Breakaway performance for side impact condition is presently not specified or evaluated by crash testing. If such a requirement is deemed necessary in the future, performance of a breakaway device should first be assessed as to the degree of compartment intrusion and then assessed for occupant collision risk.

Occupant Accelerations. For the unrestrained conditions, the occupant experiences essentially no "absolute" acceleration prior to impacting some part of the compartment surface; that is, the vehicle is accelerating relative to the occupant. At occupant impact, the degree of injury sustained by the occupant is indicated by the occupant/compartment impact velocity. Subsequent to this impact, the occupant is assumed to remain in contact with the impacted surface and then directly experiences the vehicle accelerations; the occupant may or may not sustain further injuries depending on the magnitude of these accelerations. For both lateral and longitudinal directions, it appears that the threshold value of 20 g's is survivable (i.e., AIS-3), even for long durations *(23,24,19)*.

It is noted that the acceleration signals are first filtered to a SAE J211b Class 180 and then the highest 10-ms average values are determined. Previously, SAE J211b Class 60 filter and highest 50-ms average values were used *(1)*. With other factors being equal, the new procedures will result in higher experimental values; these values will not be comparable to those developed under *TRC 191* procedures.

Recommended threshold values are summarized as follows:

Severity Indicator	Impact Direction: Longitudinal	Impact Direction: Lateral
Occupant Impact Velocity $(\Delta V)_{LIMIT}$, fps	40 (12 m/s)	30 (9 m/s)
Occupant Ridedown Acceleration $(a)_{LIMIT}$, g	20	20

These values are considered threshold limits; test results should fall well below these limits to promote safer performing appurtenances. That is, limit values may be divided by appropriate acceptance factors, F, to establish less severe design values. In developing appropriate acceptance factors, consideration must be given to the art-of-the-possible (i.e., Can a device be made, regardless of cost, to perform to the requirements?) and cost effectivess (i.e., Can the increase in safety performance level justify the added cost?). Establishment of acceptance factors is a policy decision and, therefore, beyond the purview of this report. However, recommended acceptance factors and design values are given in Table 8. It should be noted that the acceptance factors vary with the type of appurtenance and with direction of impact. Based on *TRC 191* criteria, corresponding values of occupant/compartment impact velocities are computed for several simple cases and are given in Table 8. *TRC 191* acceleration values are not given because they should not be directly compared to the revised criteria because the methods of collecting the data are different and extend over different time durations.

Data Processing. The procedures for acquiring occupant risk data given in Table 5 have evolved from several sources during the past 10 years. It is most important that these parameters be properly measured and processed; that is, the data acquisition system should conform to a recommended system and the raw data should be processed according to a proper filter class. For example, accelerations from a redirected vehicle should be processed by a SAE J211b Channel Class 180 device. Requirements for anthropometric dummy instrumentation are also delineated in SAE J211b.

Calculations. The occupant/compartment impact velocity is a value calculated from the following factors:

Vehicle collision acceleration pulse.

Distance occupant travels before impacting compartment interior. (In absence of actual measurements, an assumed distance of 2.0 ft (0.6 m) forward and 1.0 ft (0.3 m) lateral may be used.)

The expression for occupant impact velocity is

$$V_{I_{x,y}} = \int_0^{t^*} a_{x,y} dt \qquad (2)$$

where $V_{I_{x,y}}$ is occupant-car interior impact velocity in the x or y directions as noted, fps; $a_{x,y}$ is vehicle accelerations in x or y direction, fps^2; and t^* is time when occupant has traveled either 2 ft (0.6 m) forward or 1 ft (0.3 m) lateral. The time t^* is to be determined by the incremental integration

$$X,Y = \int_0^{t^*}\int_0^{t^*} a_{x,y} dt^2 \qquad (3)$$

The acceleration time plot may be manually integrated to determine the occupant impact velocity. A more convenient method is for the analog data to be converted to digital format and then processed by computer. An example of typical test data is shown in Figure 4 for a redirectional crash test. The vehicle x and y accelerations and the occupant x and y velocities and displacements are presented as a function of time after car impact. In this case, the occupant moves forward only 10.4 in. for the entire pulse and, therefore, it does not strike the compartment which is assumed to be 2.0 ft away. For the lateral or y direction, the near side occupant moves the 1.0 ft (11.8 in.) in 0.155 s and has a velocity of 17.0-fps at that time. The 17.0-fps velocity is considered to be the occupant-side door impact velocity.

In order for the acceleration to produce occupant injury, it must have at least a minimum duration ranging from 0.007 to 0.04 s, depending on body component *(19)*. Thus, vehicle acceleration "spikes" of duration less than 0.007 s are not critical and should be averaged from the pulse. An arbitrary duration of 0.010 s has been selected as a convenient and somewhat conservative time base for averaging vehicle accelerations for occupant risk assessment. This is accomplished by taking a moving 10-ms average of vehicle "instantaneous" accelerations. From Figure 4, the highest 0.010-s average acceleration in the lateral direction after occupant impact is 9.7 g.

The occupant impact velocity and the highest 10-ms average acceleration values are then compared to accepted design limits; both values should be below the design limits.

For redirectional barrier impacts and side impacts into crash cushions, the occupant impact velocity is sensitive to the actual impact conditions; that is, occupant lateral impact velocity will be higher when either the actual vehicle impact velocity and/or approach angle exceed the target values. Accordingly, when the actual vehicle impact conditions vary from the target conditions, the occupant impact velocity should be normalized to the target conditions by the expression:

$$(\Delta V)^* = (\Delta V) \frac{(V \sin\theta)_{Target}}{(V \sin\theta)_{Actual}} \qquad (4)$$

where $(\Delta V)^*$ is normalized occupant impact velocity, fps; ΔV is occupant impact velocity for actual test conditions, fps; and $(V \sin\theta)_{Target}/(V \sin\theta)_{Actual}$ is ratio of target to actual vehicle impact conditions.

Results from five occupant risk tests of longitudinal barriers are given in Table 9. Test RF-22 is on a vertical rigid concrete wall; Tests CMB-7, CMB-9, and CMB-13 are on con-

TABLE 8. RECOMMENDED OCCUPANT RISK VALUES

Impact Direction[aa] and Appurtenance Type	Occupant/Compartment Impact Velocity[b]—(fps)			Occupant Ridedown Acceleration—(g's)		
	Flail Space Recommendation		TRC 191	Flail Space Recommendation		TRC 191[e]
	$(\Delta V)_{Limit}/F^{(c)}$	$(\Delta V)_{Design}$		$(a)_{Limit}/F^{(c)}$	$(a)_{Design}$	
Longitudinal (X) Direction						
Breakaway/Yielding Supports						
• Signs and luminaire	40/2.67	15	11-16[f]	20/1.33	15	
• Timber Utility Poles	40/1.33	30	—	20/1.33	15	
Vehicle Deceleration Devices						
• Crash cushions and barrier terminals	40/1.33	30	32-39[d]	20/1.33	15	
Redirectional Barriers						
• Longitudinal, transitions and crash cushion side impacts	40/1.33	30	25-36[d]	20/1.33	15	
Lateral (Y) Direction						
Redirectional Barriers						
• Longitudinal, transitions and crash cushion side impacts	30/1.50	20	14-18[d]	20/1.33	15	

Notes:

(aa) With respect to vehicle axis.

(b) Occupant to windshield, dash or door impact velocity with occupant propelled by vehicle deceleration pulse through 2-ft forward or 1 ft lateral flail space; multiply fps by 0.305 to convert to m/s.

(c) F is acceptance factor to be established by highway agency.

(d) Values calculated from TRC 191 criteria assuming that the highest 50-ms acceleration limits of TRC 191 are constant for the duration of the event and shown here for reference.

(e) Flail space accelerations are highest 10 ms averages beginning with occupant impact to completion of pulse; TRC 191 accelerations are less severe, highest 50 ms averages or those averaged over vehicle stopping distance. These values are not comparable.

(f) From TRC 191.

PREDICTED UNRESTRAINED OCCUPANT KINEMATICS

SwRI Test—SRB-4
Test Date—10/24/1979

Vehicle Type—Mini-Auto
Nominal Impact Vel.—60.0 mph

Vehicle Wt.—2083 lbs
Nominal Impact Angle—15.0 degrees

Time-Sec.	Vehicle Acceleration—G's* AX	AY	Occupant Velocity—ft/sec VX	VY	Occupant Displacement—inches DX	DY
.000	.0	.0	.0	.0	.0	.0
.005	.3	.6	.1	.1	.0	.0
.010	.6	-.2	-.0	.1	.0	.0
.015	.1	.1	-.1	.1	.0	.0
.020	.2	-.0	-1	.1	-.0	.0
.025	-.5	.0	-.0	.1	-.0	.0
.030	-.3	.4	.1	.1	-.0	.0
.035	-1.9	5.1	.4	.9	.0	.1
.040	-.0	3.0	.3	1.4	.0	.1
.045	-2.1	3.5	.7	2.0	.1	.2
.050	-3.0	2.3	1.1	2.4	.1	.4
.055	-2.7	4.1	1.5	2.9	.2	.5
.060	2.2	3.2	1.3	3.6	.3	.7
-065	-1.9	5.2	1.6	.4	.4	.9
.070	-1.2	1.5	1.8	.6	.5	1.2
.075	-1.7	1.5	2.1	4.9	.6	1.5
.080	-2.7	3.2	2.5	5.3	.7	1.8
.085	-1.8	3.0	2.7	5.9	.9	2.2
.090	.2	3.2	2.7	6.3	1.0	2.5
.095	-2.2	3.3	3.0	.9	1.2	2.9
.100	.5	.4	3.0	7.6	1.4	3.3
.105	-1.0	.5	3.2	.3	1.6	3.8
.110	-.9	7.0	3.3	9.4	1.8	4.4
.115	-1.6	7.7	3.5	10.6	2.0	5.0
.120	-2.9	6.4	4.0	11.7	2.2	5.6
.125	-1.2	6.0	4.2	12.6	2.5	6.4
.130	-2.1	8.6	4.5	14.0	2.7	7.1
.135	1.0	.6	4.3	14.1	.0	8.0
.140	-1.4	5.5	4.6	15.1	3.2	8.9
.145	-.1	4.7	4.6	15.8	3.5	9.8
.150	.4	3.8	4.6	16.4	3.8	10.8
.155	.1	4.4	4.6	17.0 ←	4.1	11.8 ←
.160	-1.1	5.7	4.8	18.0	4.4	12.8
.165	-1.8	9.7 ←	5.0	19.5	4.7	13.9
.170	-.4	7.8	5.1	20.7	5.0	15.1
.175	-1.5	8.4	5.3	22.2	5.3	16.4
.180	-.7	8.1	5.4	23.4	5.6	17.8
.185	-1.9	5.6	5.7	24.4	5.9	19.2
.190	.5	5.1	5.7	25.2	6.3	20.7
.195	-.2	4.6	5.7	26.0	6.6	22.3
.200	.4	3.3	5.6	26.5	7.0	23.8
.205	-.3	1.4	5.7	26.8	7.3	25.4
.210	-.5	1.1	5.8	27.0	7.7	27.1
.215	.2	.7	5.8	27.1	8.0	28.7
.220	.6	.7	5.7	27.2	8.3	30.3
.225	-1.2	.5	5.8	27.3	8.7	31.9
.230	.5	-.2	5.7	27.3	9.0	33.6
.235	.2	-1.8	5.8	27.0	.4	35.2
.240	-.6	-1.1	5.8	26.9	9.7	36.8
.245	-.4	.6	5.9	26.9	10.1	38.4
.250	-.4	-.5	6.0	26.8	10.4	40.0

Summary
$V_y = 17.0$ fps
$A_y = 9.7$ g
V_x, A_x Non-critical as occupant moves less than 24 in.

*10 ms moving average; analog signal sampled at minimum rate of 1000 per second.

Figure 4. Evaluation of typical redirecting barrier for occupant risk.

TABLE 9. TYPICAL LONGITUDINAL BARRIER SEVERITY TESTS (2250 lb vehicle/60 mph/15 deg.)

SwRI Crash Test*	RF-22	CMB-7	CMB-9	CMB-13	SRB-4
Barrier Type	Vert. Conc. Wall	GM Safety Shape	NJ Safety Shape	"F" Safety Shape	Self-Restoring Thrie Beam
Test Conditions					
Vehicle Mass, lb.	2140	2250	2250	2250	2083
Impact Speed, mph	61.9	57.1	58.9	56.4	54.7
Approach Angle, deg	18.3	16.5	15.5	14.3	17.1
TRC 191 Evaluation					
Vehicle Accelerations					
(highest 50 ms avg—g)					
Lateral/max. limit	16.1/5	4.6/5	6.0/5	7.3/5	9.7/5
Longitudinal/max. limit	8.2/10	3.4/10	0.9/10	3.8/10	3.0/10
TRC 191 Appraisal	Poor (lat accel)	Good	Marginal	Marginal	Poor
Flail Space Evaluation					
Occupant Lat. Impact Velocity-fps					
Test	28.0	22.4	17.7	16.2	17.0
Normalize**	22.4	21.4	17.5	17.8	16.4
Design limit***	20.0	20.0	20.0	20.0	20.0
Occupant Ridedown Lat. Accel.					
(highest 10 ms avg—g)					
Test	8.6	4.8	4.9	4.6	9.7
Design limit***	15.0	15.0	15.0	15.0	15.0
Flail Space Appraisal	Poor	Marginal	Good	Good	Good

*Test results from DOT contracts: FH-11-8100, Test RF-22; FH-11-8130, Test CMB-7, -9 and -13; FH-11-9486, W.O. 1, SRB-4.

**Occupant impact velocities normalized by the factor $\frac{(V \sin \theta) \text{ Target}}{(V \sin \theta) \text{ Actual}}$

***As suggested in Table 8.

crete shape shapes; and Test SRB-4 is on a semiflexible metal beam barrier.

Vehicle Trajectory

Vehicle trajectory hazard is concerned with potential risk to other traffic. Depending on the type of appurtenance and potential site applications, there are several unacceptable appurtenance performance characteristics with respect to the vehicle after-collision trajectory:

1. A vehicle that is abruptly decelerated while partially in a traffic lane. This is a problem for appurtenances that may be sited within a vehicle-width of the traveled way and in which vehicle snagging on an element of a redirectional device or vehicle rebounding or spinning out after end-on collision with a crash cushion occurs.
2. A vehicle that is abruptly redirected back into the traffic stream. This may be caused by substantial localized barrier lateral deformation at the point of impact or pocketing.

These characteristics may pose panic situations to other traffic and may initiate multicar collisions.

In general, the ideal after-collision vehicle trajectory performance goal for all appurtenances should be that the vehicle trajectory and final stopping position should not intrude into the adjacent or opposing traffic stream. For breakaway or yielding supports, the trajectory of a vehicle after it has collided with a test article that satisfies structural adequacy and occupant risk requirements is generally away from the traffic stream and, hence, is normally noncritical. For end-on impacts into crash cushions and barrier terminals that function as crash cushions, the final position of the vehicle should be next to the test device.

For redirectional performance tests of length of need, transitions, terminals, and side hits on some crash cushions, the after-collision trajectory is more difficult to assess. The after-collision trajectory may be one of the least repeatable performance factors because of variation in method and timing of brake application; further, variables that are in part related to the specific model of vehicle selected for tests such as damage to vehicle suspension, tires, etc., may greatly alter the vehicle stability and path. Moreover, because driver response in avoiding secondary collisions is not simulated in the crash tests, it seems inappropriate to predict in-service performance based on the complete test trajectory. For these reasons, trajectory evaluation for redirectional type of tests is focused on the vehicle at the time it loses contact with the test article, and the subsequent part of the trajectory is not presently evaluated. At time of contact loss, two vehicle properties are evaluated: (1) exit angle and (2) speed change during appurtenance contact. The vehicle exit or heading angle is probably the more important property as a measure of potential hazard to other traffic. Although ideal performance would be for the vehicle to exit with a path parallel to the installation, an upper limit of 60 percent of the impact angle is recommended. On the other hand, speed change is a trajectory hazard factor only when the redirectional barrier is very near the traffic stream or when the vehicle is redirected abruptly back into the traffic stream; in such a case, a small speed change would minimize possible traffic conflicts. On the other hand, while vehicle snagging during redirection may not always pose a hazard to following traffic, it is normally an indication of marginal or erratic appurtenance performance and an indication that excessive damage repair cost may be required for the test article if placed in service; hence, a maximum speed change of 15 mph (24 kph), as measured with respect to the vehicle longitudinal axis, is recommended. Both the exit angle and speed change limits are new with the document; there is no assurance that existing hardware or certain classes of appurtenances will perform within these limits.

For longitudinal barrier terminals, vehicle trajectory behind the test article is acceptable, in theory, since this segment is beyond the warranted length-of-need.

REPORT

To facilitate the comparison of tests performed by different agencies, a uniform reporting format is suggested. The format lists the items to be reported and includes recommendations for reporting findings.

An example table of contents, shown in Figure 5, includes major elements of a report.

In presenting findings, at least three agencies are presently using a test summary plate that combines the most important features of a test on one page. An example of the summary plate is shown in Figure 6. The use of such a summary plate is encouraged to permit the reader to form a quick general impression of the test.

IN-SERVICE EVALUATION

In-service monitoring of new safety appurtenances has been recommended for several years *(4)* and has been practiced by FHWA and several highway agencies for selected devices *(13)*. However, the extent and scope of these monitoring efforts have varied widely, thus leaving the highway engineer with incomplete information to judge the performance of a new device or the relative merit of two or more devices. Systems and devices have been accepted as "operational" based on the absence of negative feedback from the field after an undefined observation period. In recent years, systems and devices have been deemed operational by consensus of national panels *(4,18)*, and these have been formally accepted by FHWA for use on federal-aid projects. FHWA has approved other designs on a project-by-project basis.

In-service evaluation guidelines are intended to encourage a cautious, systematic introduction of new safety hardware. With careful monitoring, unanticipated problems and design deficiencies can be identified before the hardware has been installed in an excessive number of sites. Moreover, all the affected departments will have an opportunity to observe the

I. INTRODUCTION

- A. Problem
- B. Background/Literature Search
- C. Objectives/Scope of Research

II. TECHNICAL DISCUSSION

- A. Test Conditions (Overview)
  1. Test Facility
  2. Test Article—Design and Construction
  3. Test Vehicles
  4. Data Acquisition Systems
  5. Test Parameters
- B. Test Results (Factual only)
  1. Impact Description/Vehicle Behavior
  2. Barrier Damage/Debris Patterns
  3. Vehicle Damage
  4. Dummy Behavior
- C. Discussions of Test Results (Results compared to the Dynamic Performance Factors)
  1. Occupant Risk
  2. Structural Adequacy
  3. Vehicle Trajectory Hazard

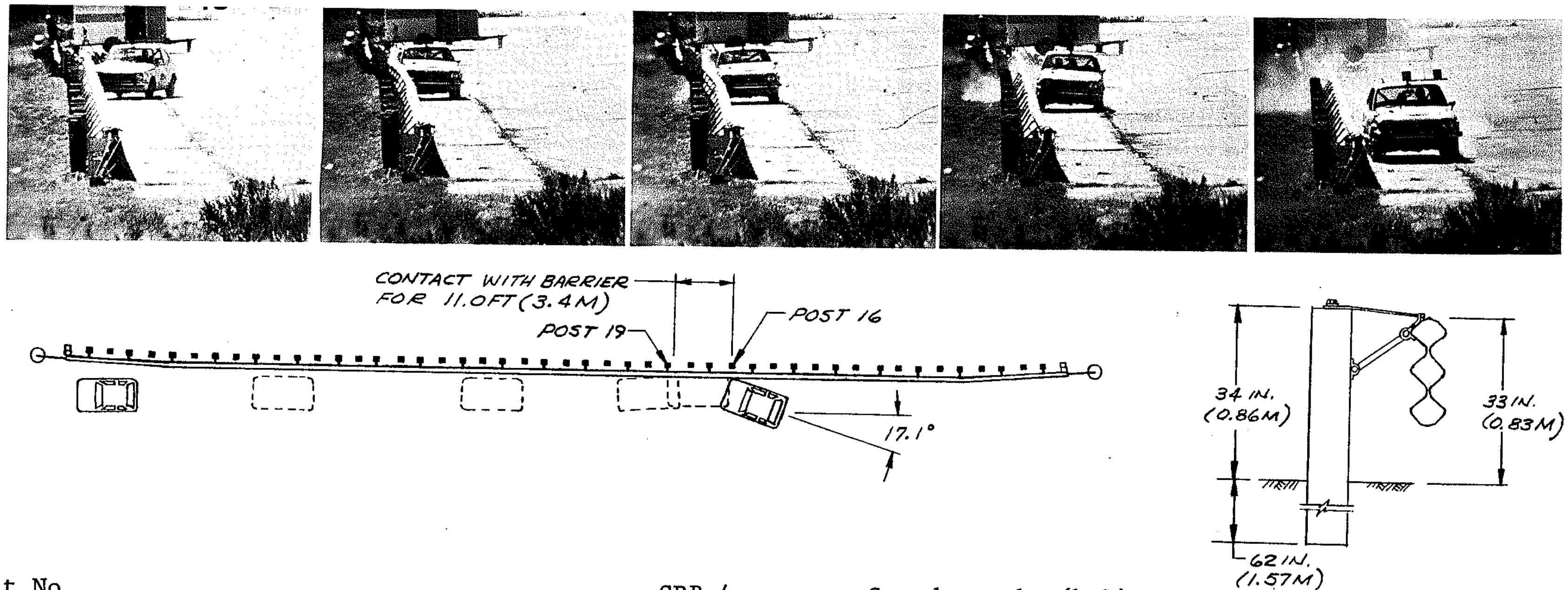
III. CONCLUSIONS AND RECOMMENDATIONS

IV. REFERENCES

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. Appurtenance Construction Experience and/or Installation Procedures (if unusual)
- G. Accident Experience (if available)

Figure 5. Suggested table of contents for crash test report.



Test No.	SRB-4
Date	10/24/79
Installation	
Drawing No.	SwRI 4308-2
Length - ft (m)	200 (61)
Beam Rail	
Member	12 ga tubular thrie beam
Length - ft (m)	25 (7.6)
Maximum Deflections	
Dynamic - in. (m)	10.8 (0.27)
Permanent - in. (m)	0 (0)
Post	
Material	Wood
Dimensions - in. (m)	8 x 8 x 96 (0.2 x 0.2 x 2.4)
Embedment - in. (m)	62 (1.6)
Spacing - ft (m)	4.2 (1.3)
Soil Type and Condition	S-1/dry
Vehicle	
Model	1974 Honda Civic
Mass - lb (kg) Test Inertia	1753 (795)
Dummy	330 (150)
Gross	2083 (945)

Speed - mph (kph)	
Impact	54.7 (88.0)
Exit	45.5 (73.2)
Angle - deg	
Impact	17.1
Exit	2.0
Occupant Impact Velocity - fps (m/s)	
Forward	n/a
Lateral	17.0 (5.2)
Occupant Ridedown Accelerations - g's	
Forward	n/a
Lateral	9.7
Vehicle	
Rebound Distance - ft (m)	3 (0.9)
Damage	
TAD	1-RD-2
VDI	01RFMS1

Figure 6. Example of vehicle crash test results summary.

performance of the device with respect to their operations. For instance, there may be minor design changes suggested by the maintenance groups that may reduce normal maintenance or damage repair costs; also, substitution of material or fasteners could ease the problem of a large inventory of spare parts. Care should be taken not to make changes in design details which could adversely affect safety performance without verification of adequate performance through full-scale crash testing or other acceptable means.

The in-service evaluation guidelines are intended to encourage a more consistent and thorough implementation of new devices and to promote a more direct and systematic process in demonstrating the operational status of safety appurtenances.

REFERENCES

1. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances." Transportation Research Circular 191 (Feb. 1978) 27 pp.
2. Bronstad, M. E., and Michie, J. D., "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances." NCHRP Report 153 (1974) 19 pp.
3. Highway Research Board Committee on Guardrails and Guide Posts, "Full-Scale Testing Procedures for Guardrails and Guide Posts." HRB Circ. 482 (Sept. 1962).
4. Michie, J. D., and Bronstad, M. E., "Location, Selection, and Maintenance of Highway Traffic Barriers." NCHRP Report 118 (1971) 96 pp.
5. Chisholm, D. B., and Viner, J. G., "Dynamic Testing of Luminaire Supports." Report No. FHWA-RD-73-55, Federal Highway Administration, Washington, DC (1972).
6. Bronstad, M. E., "Multiple Service Level Bridge Railings—Performance and Design Criteria." National Cooperative Highway Research Program Project 22-2 (2) (1981).
7. "Vehicle Damage Scale for Traffic Accident Investigators." Traffic Accident Data Project Bulletin No. 1, National Safety Council (1968).
8. "Collision Deformation Classification, Recommended Practice J224a." Society of Automotive Engineers, New York (1972).
9. Michie, J. D., "Collision Risk Assessment Based on Occupant Flail Space Model." Presented at Transportation Research Board Annual Meeting, National Academy of Science (Jan. 1981).
10. Viner, J. G., "Vehicle Downsizing and Roadside Safety Hardware." Proceedings, 23rd Annual Conference of American Association of Automotive Medicine, Louisville, Ky. (Oct. 1979).
11. Federal Motor Vehicle Safety Standard No. 214, Side Impact Protection (Upgrade), Advance Notice of Proposed Rulemaking, Washington, DC (Dec. 1979).
12. Labra, J. J., "Impact Attenuators for Heavy Vehicles—A Feasibility Study." Phase I Final Report, DOT-FH-11-9342, Federal Highway Administration, Washington, DC (Aug. 1980).
13. Viner, J. G., and Boyer, C. M., "Accident Experience with Impact Attenuation Devices." Report No. FHWA-RD-73-71, Federal Highway Administration, Washington, DC (1973).
14. "Instrumentation for Barrier Collision Tests, SAE Standard J211b." 1973 Handbook, Society of Automotive Engineers, New York (1974).
15. Murray, W. M., and Stein, P. K., "Strain Gage Techniques." Engineering Extension, Dept. of Engineering, Univ. of California and Soc. for Experimental Stress Analysis (1960).
16. "Performance Characteristics of Bonded Resistance Strain Gages." E251-67, American Society for Testing Materials.
17. U.S. Department of Transportation, "Occupant Crash Protection in Passenger Cars." FMVSS 208, Federal Register, DOT NHTSA (49 CFR Part 571).
18. "Guide for Selecting, Locating, and Designing Traffic Barriers." American Association of State Highway and Transportation Officials, Washington, DC (1977).
19. Snyder, R. G., "State-of-the-Art—Human Impact Tolerance.", SAE 700398 (rev. Aug. 1970); reprinted from 1970 International Automobile Safety Conference Compendium (May 1970).
20. Begeman, P. C., King, A. I., Weigt, P., and Patrick, W., "Safety Performance of Asymmetric Windshields." Society of Automotive Engineers, Inc. Paper No. 780900 (1978).
21. Kay, S. E., Pickard, J., and Patrick, W., "Improved Laminated Windshield with Reduced Laceration Properties." 17th Stapp Conference (1973).
22. Hartemann, F., Thomas, C., Foret-Bruno, J., Henry, C., Fayon, A., and Tarriere, C., "Occupant Protection in Lateral Impacts." Twentieth Stapp Crash Conference (1976).
23. Kornhauser, M., and Gold, A., "Application of Impact Sensitivity Method to Animate Structures." Impact Acceleration Stress, NAS National Research Council Publication 977 (1961) pp. 333-344.
24. Chi, M., "Assessment of Injury Criteria in Roadside Barrier Tests." Report No. FHWA-RD-75-74, Federal High-

way Administration, Washington, DC (Feb. 1976).
25. The Abbreviated Injury Scale (AIS-80). The American Association for Automotive Medicine, Morton Grove, IL 60053 (1980).
26. "Standard Specifications for Highway Bridges AASHTO." 1977 edition and related interims.
27. Olson, R. M., Ivey, D. L., Post, E. R., Gunderson, R. H., and Cetiner, A., "Bridge Rail Design: Factors, Trends, and Guidelines." NCHRP Report 149 (1974) 49 pp.
28. "A Guide to Standardized Highway Barrier Rail Hardware." Technical Bulletin No. 268B, Joint Report from AASHTO, AGC, ARTBA Task Force 13, American Road and Transportation Builders, Washington, DC (June 1979).
29. Michie, J. D., Calcote, L. R., and Bronstad, M. E., "Guardrail Performance and Design." NCHRP Report 115 (1971) 115 pp.
30. Lawrence, L. R., and Hatton, J. H., Jr., "Crash Cushions—Selection Criteria and Design." Federal Highway Administration, Washington, DC (Sept. 1975).
31. "A Guide to Standardized Highway Lighting Pole Hardware." Technical Bulletin No. 270, Joint Report from AASHTO, AGC, ARTBA Task Force 13, American Road and Transportation Builders, Washington, DC (Apr. 1980).
32. "Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals." AASHTO Subcommittee on Bridges and Structures (1975).
33. "AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals." FHWA Notice N 5040.20, Federal Highway Administration, Washington, DC (July 14, 1976).
34. Edwards, T. C., Martinez, J. E., McFarland, W. F., and Ross, H. E., Jr., "Development of Design Criteria for Safer Luminaire Supports." NCHRP Report 77 (1969) 82 pp.
35. "Cost-Effectiveness of Small Highway Sign Supports." FHWA Contract FH-11-8821, Report No. FHWA/RD-80/502, Federal Highway Administration, Washington, DC (1980).
36. Labra, J. J. (Southwest Research Institute), "Development of Safer Utility Poles." Contract DOT-FH-11-8909, Final Report (Feb. 1980).
37. "Laboratory Procedures to Determine the Breakaway Behavior of Luminaire Supports in Mini-Sized Vehicle Collisions." RFP No. DTFH61-80-R-00354, Federal Highway Administration, Washington, DC (1981).
38. Buth, E., Noel, J., Arnold, H., and Hirsch, J., "Development of Safer Bridge Railing Designs." Final Report Draft, FHWA Contract FH-11-9181, Federal Highway Administration (Feb. 1981.)
39. Shaw, M. (Dynamic Science, Inc.), "Assessment of Performance of Impact Attenuators Mounted on Curbs." FHWA Contract FH-11-9287 Monthly Report, Federal Highway Administration (Feb. 1981).

APPENDIX

ANALYTICAL AND EXPERIMENTAL TOOLS

Design, synthesis, and development of a new appurtenance system is not a straightforward procedure but is an iterative process requiring tradeoffs among sometimes conflicting safety performance requirements, environmental considerations, and costs. In this appendix, analytical and experimental tools (excluding full-scale crash tests) that are typically used in devising and evaluating new appurtenances are presented and discussed. Also, application and limitations of these techniques are presented.

USEFUL TECHNIQUES

Structural Design

The primary design objective of longitudinal barrier and crash cushions is the safety performance with errant vehicles, but there are other design considerations pertaining to economy, environment, maintenance, and operational needs.

On the other hand, safety performance during vehicle collision is not the reason for installing supports for signs and luminaires. If lighting or information for the motorist is not needed, the appurtenance should not be located on the roadside. Hence, the primary design objective is to support the luminaire or sign blank for environmental loading. Fortunately, engineers have been able to develop breakaway and yielding supports that will satisfy both the primary and secondary objectives.

Structural loading and design procedures are contained in civil engineering textbooks, AASHTO design manuals, and research publications. Primary references are given in Table A-1 for each type of appurtenance. The designer/developer should consult these references as a first step along with the appropriate appurtenance manufacturer. For safety considerations, the references will aid the developer in proportioning the device for subsequent evaluation steps.

Static Tests

During an early stage of development, certain critical details and connections of an appurtenance may require

TABLE A-1. SOURCES FOR APPURTENANCE INFORMATION

Appurtenance		Principal Reference
I.	Longitudinal Barriers	
	A. Bridge Rails	18, 26, 27, 28
	B. Guardrails	29, 18, 27, 28
	C. Median Barriers	18, 27, 28, 29
	D. Terminals	18, 28
II.	Crash Cushions	30, 18
III.	Breakaway or Yielding Supports	
	A. Luminaire	5, 31, 32, 33, 34
	B. Sign Supports	32, 33, 35
	C. Utility Poles	36

strength/deflection evaluation. Many appurtenances are expected to function at or near ultimate capacity of the materials, well beyond typical design ranges such as elastic limits. In general, these tests are special and do not conform to standard tests suggested by ASTM.

These tests will have one of the following objectives:

1. Demonstrate appurtenance system under simulated environmental loading.

2. Evaluate ultimate strength of critical connections.

3. Develop load/deflection properties for subsequent computer model simulations.

In general, it is anticipated that quality control of materials used in the operational system may vary extensively. Where possible, safety performance behavior should not rely heavily on material properties that cannot be carefully controlled. For instance, energy to fragment a frangible transformer base can vary more than 100 percent with even minor changes in heat treatment of the aluminum alloy. Soil foundation conditions can change from a rigid boundary (frozen soil) to a plastic hinge (wet clay). In contrast, tensile strength and elastic modulus of wire rope vary within a narrow performance band.

Even at this stage, the developer should be aware of value engineering by avoiding overspecifying materials, especially components that are noncritical. Moreover, he should ensure that materials used in the prototypes are typical and routinely acquired materials and not "Sunday samples." Where possible, the developer should use standard hardware elements for initial economy and to minimize the maintaining of special inventory *(28)*.

Computer Simulations

A number of computer programs have been developed that simulate vehicle dynamics and kinematics during interactions with highway appurtenances. Also, several models have been developed to simulate occupant dynamics during impact. The more important of these codes and models are given in Table A-2. The models vary in complexity of mathematical analog, type of appurtenance investigated, and class of vehicle. For instance, the vehicle model in HVOSM has 11 degrees of freedom and is three-dimensional. In contrast, the vehicle in BARRIER VII is two-dimensional.

Model results are sensitive to vehicle parameters that are sometimes difficult to obtain or approximate. Vehicle moments of inertia, crush properties, and suspension stiffness properties are generally not published and must be determined experimentally. Moreover, barriers exhibit large deflections during typical collisions that are difficult to predict because of uncontrolled features such as joint looseness, soil variation, and unstable structure behavior.

Most of the computer programs in Table A-2 have been correlated with crash tests for one or more cases. For the validated cases, the computer output can be most helpful to the appurtenance designer by providing sometimes unique insight into the collision event. Where the program has been validated for two distinct impact conditions, it can be used with a high degree of confidence in investigating conditions that are bracketed by the validated conditions. Investigation of impact conditions outside the validated range can provide insight to potential dynamic behavior; however, the engineer should use care in these extrapolations and view the findings with caution.

Laboratory Dynamic Tests

In addition to full-scale crash tests presented in Chapter Two, there are three types of dynamic test methods to evaluate and study safety appurtenances: gravitational pendulum, drop mass, and bogie vehicle.

Gravitational Pendulum

The facility is characterized by a striking mass that swings in a circular arc suspended by cables or by rigid arms from a main frame. The specimen is generally mounted in an upright manner. Mass velocity at impact is governed by the formula $V_i = \sqrt{2gh}$ subject to minor corrections due to friction and aerodynamic losses, where h is the drop height of the mass. For an impact speed of 20 mph (8.9 m/s), a drop basic height of 13.36 ft (4.07 m) is required. The swing radius is usually considerably larger than the drop height.

Initially, the pendulum mass was faced with a 4.0-in. (0.1-m) radius rigid cylinder and a 1-in. (0.025-m) thick rubber surface. In 1976, the rigid face was replaced by a crushable nose shown in Figure A-1 that is intended to simulate the crush characteristics of a 2250S subcompact passenger vehicle. In the event that a different design vehicle is selected, such as 1800S, the mass and crush characteristics will be changed. Thus, the nose configuration shown in Figure A-1 will no longer be appropriate.

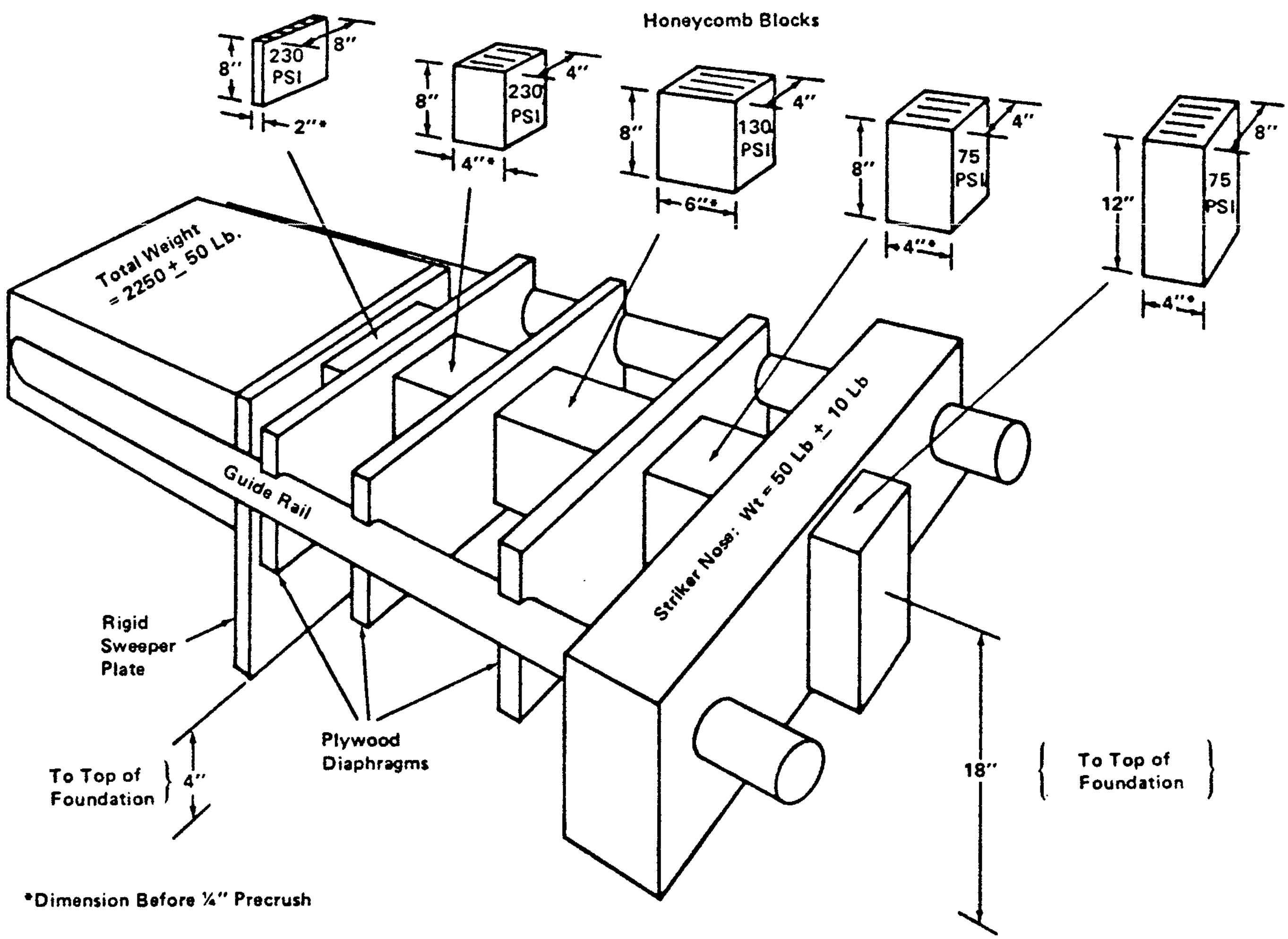
Drop Mass

This facility is characterized by a rigid striking mass that falls vertically to impact point, as opposed to swinging radially. The specimen is mounted horizontally or 90 deg from normal and attached to a rigid test fixture plate. Impact veloc-

TABLE A-2. SUMMARY OF HIGHWAY SAFETY COMPUTER PROGRAM

Name	Developer/Date of Last Mod	Principal Application	Model	Validation	Documentation Availablility	Comment
HVOSM	CALSPAN/ 1976	Simple vehicle/rigid directive barrier	3D Lump Mass Vehicle	Extensive	FHWA (R & D)	Excellent wheel/suspension system analog; simplified vehicle body crush analog.
BARRIER VII	Univ. of Cal./ 1973	Simple vehicle/flexible redirective barrier	2DFinite Element Model	Extensive	FHWA (R & D)	For cases where roll and pitch of vehicle are negligible.
RVA	ENSCO/ 1975	After-impact vehicle rollover potential	3D Rigid Body	Limited	FHWA (R & D)	Nondeformable single-unit vehicle and barrier—very inexpensive to run.
RVA2	SwRI/ 1979	Modified RVA to consider cargo shift during impact	3D Rigid Body	Limited	SwRI	Requires judgment on where cargo will shift to during impact.
BARRIER VII/RVA	ENSCO/ 1975	3D vehicle/2D flexible barrier interaction	3D Vehicle-2D Barrier	Limited	FHWA (R & D)	RVA vehicle model incorporated into BARRIER program—vehicle having force-deformation characteristics.
BARRIER VIII	ENSCO/ 1975	2D tractor trailer/flexible barrier interaction	2D Tractor Trailer-2D Finite Element Barrier	Limited	FHWA (R & D)	Modified BARRIER program designed to consider tractor trailer/barrier interaction—no trailer barrier impact capability.
GUARD	IITRI/ 1976	Simple vehicle with detailed bumper modeling capability; flexible or rigid barrier systems	3D FEM Vehicle and Barrier Model	Limited	FHWA (R & D)	Developed in part from CRUNCH program—simplistic wheel/suspension model.
CRUNCH	IITRI/ 1977	Articulated vehicle/ flexible or rigid barrier capabilities	3D FEM	Limited	FHWA (R & D)	Similar to GUARD program but with articulated vehicle
TIGER	SwRI/ 1970	Simple vehicle after-impact kinematics	3D-6 DOF Vehicle-2D Barrier	Limited	SwRI	Limited to uniform post spacing for barrier response.
USIN	Univ. of Cinn./ 1976	3D occupant response prior to compartment impact	Multiple Rigid Body Segment Model (MRBSM)	Limited	FHWA (R & D)	Lacks occupant/vehicle interaction capabilities.
CVS	CALSPAN/ 1975	3D after-impact occupant response	MRBSM	Limited	NHTSA	Extensive modifications have been made to program (latest Version XIX),
PROMETHEUS 2	Univ. of Michigan/1971	2D pedestrian impact response	MRBSM	Limited	Univ. of Michigan	Eleven-segment model.
HSRI Crash Victim Simulator	HSRI/	3D after-impact occupant response	MRBSM	Limited	HSRI Michigan	Six-body segment—17 DOF occupant model with body-vehicle interior interaction capacity.
TTI Auto Passenger	TTI/ 1970	3D after-impact occupant response	MRBSM	Limited	TTI/College Station, Tex.	Twelve-body segment—31 DOF model—detailed passenger compartment.
CRASH	CALSPAN/ 1976	2D vehicle impact model	Vehicle	Limited	NHTSA	Reconstruction of accident speeds on the highway (as a preprocessor for the SMAC program)
SMAC	CALSPAN/ 1975	Rigid body motion—2D vehicle (no barrier)	Vehicle	Limited	NHTSA	Model used for accident reconstruction.
UMVCS-1	Univ. of Michigan/1977	Simulate vehicle deformation	Vehicle	Limited	Univ. of Michigan	Simulates large dynamic vehicle deformation due to impact.

ENSCO Soft-Nosed Pendulum Configuration



Layout of modified crushable nose proposed for pendulums and bogies (FH-11-9194, ENSCO) (five-module nose).

Metric Conversions: 1 ft = 0.3048 m 1 lb = 0.454 kg 1 mph = 1.609 km/h 1 Δmv (lb-sec) = 4.45 Ns

Figure A-1. Layout of crushable nose for pendulums and bogies.

ity is governed by the formula $V_i = \sqrt{2gh}$ where h is the drop height.

Bogie Test

The bogie vehicle is defined as a structure mounted on four wheels and with mass equivalent to that of a selected passenger vehicle. The bogie vehicle is steered by rails, guide cable, remote control, or other means to strike the specimen. The bogie vehicle may be accelerated to impact speed by a push or tow vehicle, by self-power or by stationary windlass. A crushable or otherwise deformable nose is mounted on the front of the bogie.

The specimen is usually mounted to a rigid fixture plate in a normal vertical fashion, although it may be installed on a typical footing.

COMPARISON OF TECHNIQUES

Applications and limitations of appurtenance development techniques are given in Table A-3.

TABLE A-3. APPLICATIONS AND LIMITATIONS OF APPURTENANCE DEVELOPMENT TECHNIQUES

Appurtenance Development Technique	Principal Areas of Application	Possible Limitations
1. Structural Design Methods	• Preliminary and final design of appurtenance for environment and non-collision performance • Preliminary design of appurtenance for vehicle collision performance • Analysis of connections, material properties requirement and foundation design	• Dynamics and kinematics of appurtenance and collision vehicle are not addressed • Collision severity in terms of occupant injuries and fatalities is not addressed
2. Static Tests (quasi-static)	• Mechanical properties of unique shapes, connections, new materials • Validation of structural design features • Quality control of critical material properties • Develop input values for computer programs	• Dynamic properties not examined • Generally applicable to samples, connections, and small subassemblies; entire system is not accommodated
3. Computer Simulations	• Study interrelations of appurtenance and vehicle dynamics and kinematics • Study interrelations of vehicle dynamics and occupant dynamics • Study sensitivity of appurtenance, vehicle and site conditions on vehicle/appurtenance dynamic interactions	• Program should be validated by full-scale crash tests for specific conditions that bracket the conditions under study • Input parameters are sometimes not available and must be estimated • For practical and economic reasons, programs model only major appurtenance/vehicle features. • Sometimes minor features decide the performance
4. Laboratory Dynamic Tests		
A. Gravitational Pendulum	• Compliance test for single-leg, breakaway supports • Evaluation of breakaway mechanisms • Force/deformation of guardrail post/soil interaction • Dynamic strength of anchor systems • Dynamic properties of barrier subsystems	• Impact speed of less than 25 mph • Dual-leg supports, upper-hinge mechanism are not examined • Simulates only center of bumper hit on support • Trajectory of article not reproduced • Base-bending support not applicable • Crushable nose must be tuned for type and width of specimen
B. Drop Mass	• Quality control test of breakaway component • Test can be performed in a confined, indoor space	• Same limitations as for pendulum • For breakaway base, attached pole introduces artifact moment into base due to gravity
C. Bogie Vehicle Test	• Compliance test for single or multi-leg breakaway support • Repeatable test vehicle suspension, nose crash, and other dynamic properties • Low-cost, high-speed (0-60 mph) experiments	• If not properly designed, will not approximate representation of a vehicle characteristic of interest • Historically, bogie vehicle designs have been appropriate for testing limited variation in appurtenance
D. Vehicle Crash Test	• Compliance test for all appurtenances • Investigation of unusual conditions • Most direct tie to actual highway collisions • Final proof test	• Relatively expensive to perform • Requires extensive capital facilities • Deliberate and slow to perform • Test results pertain to the specific vehicle model tested and may not be applicable to other vehicles