NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **153**

RECOMMENDED PROCEDURES FOR VEHICLE CRASH TESTING OF HIGHWAY APPURTENANCES

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RECOMMENDED PROCEDURES FOR VEHICLE CRASH TESTING OF HIGHWAY APPURTENANCES

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AREAS OF INTEREST:

HIGHWAY DESIGN
BRIDGE DESIGN

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

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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 the full-scale vehicle crash testing of highway appurtenances, 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 on the part of design engineers for a choice of effective highway traffic barrier systems. The problem continues to receive extensive attention with the development of new systems and improvements to old ones. Full-scale impact testing is the most common method of evaluating traffic barriers and other safety appurtenances. A number of agencies in the United States are conducting such tests, and there is a need for more uniformity in the procedures and evaluation criteria used.

Therefore, one of the objectives under the second phase of NCHRP Project 22-2, "Traffic Barrier Performance and Design," at Southwest Research Institute, was development of uniform barrier testing procedures and criteria. The safety appurtenances covered by this document include guardrails, median barriers, bridge rails, crash cushions, and breakaway supports.

This report consists of two parts, and is based on a synthesis of existing information on barrier technology, test methods, and human tolerance. Part I contains the recommended procedures for the testing: Part II, a commentary on the procedures, is intended to provide insight into the rationale used in arriving at the decisions reflected in Part I.

The agency worked jointly with an ad hoc committee of NCHRP Advisory Panel C22-2 consisting of Malcolm D. Graham, New York State Department of Transportation; Eric F. Nordlin, California Department of Transportation; Charles Y. Warner, Brigham Young University; and John G. Viner, Federal Highway Administration. Although the report originated with the research agency, each recommendation has the consensus endorsement of the ad hoc committee and NCHRP Advisory Panel C22-2, which had over-all advisory responsibility. Generally, where recommendations are founded on less than clear-cut evidence, the judgment of the advisory groups prevailed.

The first two drafts of this document were mailed to about 80 individuals, of whom more than 50 submitted reviews. The ad hoc committee met twice and the full panel once to discuss the report and consider the review comments received.

Parts of this document will, on occasion, need to be revised. 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.

Other research continuing under the second phase of NCHRP Project 22-2 entails further development of the breakway cable terminal for guardrail and median barrier end treatments. This work is scheduled for completion in mid 1975.

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ACKNOWLEDGMENTS

The work reported herein was conducted by the Department of Structural Research, Southwest Research Institute, San Antonio, Texas. Jarvis D. Michie, Section Manager, served as principal investigator. He was assisted by Maurice E. Bronstad, Senior Research Engineer.

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 Panel C22-2, 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 Panel C22-2, consisting of M. D. Graham, New York Department of Transportation; E. F. Nordlin, California Department of Transportation; C. Y. Warner, Brigham Young University; and J. G. Viner, FHWA (Office of Research), reviewed the draft comments in detail with the authors and recommended changes in the document.

Acknowledgment also is made to Dr. R. C. DeHart, Southwest Research Institute, for his technical and administrative contributions.

RECOMMENDED PROCEDURES FOR VEHICLE CRASH TESTING OF HIGHWAY APPURTENANCES

SUMMARY

Procedures are presented for conducting passenger vehicle crash tests 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 of roadside appurtenances so that highway engineers may confidently compare safety performance of two or more designs that are tested by different agencies. The procedures are guidelines that describe how an appurtenance should be tested and evaluated. The procedures are directed to only the safety or dynamic performance of an appurtenance; other service requirements of economics and aesthetics are not considered in the evaluation.

These procedures are devised to subject highway appurtenances to severe or worst passenger vehicle impact conditions rather than to "typical" or the more predominant highway situations. Appurtenances developed for these conditions are believed to provide a moderate level of protection to occupants of large vehicles. 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; an idealized soil is specified although appurtenances are often founded in poor soil 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.

Guidelines are presented for evaluating safety performance. Three appraisal factors are (a) structural adequacy, (b) impact severity, and (c) vehicle trajectory hazard. Depending on the appurtenance's function, it should contain, redirect, and/or permit penetration of the impacting vehicle in a predictable manner to satisfy structural adequacy requirements. Impact severity relates to the degree of hazard to which occupants of the impacting vehicle would be subjected and is measured in terms of vehicle accelerations and momentum changes. Vehicle trajectory hazard relates to the probable involvement of other traffic because of the postcrash path or position of the impacting car.

The highway engineer should be aware 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, he should recognize the limitations of the tests and exercise care in interpreting the results.

PART I. RECOMMENDED PROCEDURES

I. SCOPE

A. Purpose

The procedures recommended herein deal with testing and evaluating the safety of roadside appurtenances by crashing passenger vehicles into them. Safety performance of the test article is primarily evaluated according to the degree of hazard that occupants of the impacting vehicle would be subjected to and the probable involvement of other nearby traffic. Other service requirements of the appurtenance, such as economics and aesthetics, are beyond the scope of these procedures.

B. Appurtenances

These procedures are applicable to the following highway appurtenances:

- Longitudinal barriers, including guardrails, median barriers, bridge railings, transitions, and terminals.
- Crash cushions.
- Breakaway or yielding supports, including those for signs, luminaires, and other purposes.

C. Previous Recommendations

These procedures are intended to update recommendations outlined in 1962 by the Highway Research Board Committee on Guardrail and Guideposts in *HRB Circular 482* (*1*).

II. TESTING FACILITY

A. Area

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

B. Soil

For both longitudinal barriers employing soil-embedded posts and breakaway or yielding structures, the embedment soil shall be a low-cohesive, well-graded crushed stone or broken gravel with particle size distribution given in Table 1. For localized use of the recommended soil, the depth and surface radius of the embedment material shall be a minimum of 1.5 times the device or post embedment length, with a maximum depth and surface radius of 6 ft (1.8 m). The material shall be compacted initially, and the disturbed material recompacted between tests, according to AASHTO T99-70, Method C or D. A crash test should not be performed when the embedment soil is saturated with moisture or the ground is frozen.

C. Embedment Practice

The method used in embedding test articles shall be typical of highway construction practice. Preferably, barrier posts and base bending supports shall be driven, although inserting these articles in drilled holes and backfilling is permitted. The footings for breakaway supports shall be representative of highway design practice and shall be sized for minimum wind loading; the footing is considered an integral part of the test article.

D. Special Structure

A structure simulating a bridge deck shall be used as a foundation for a bridge rail test.

III. TEST ARTICLE

A. General

1. Materials

Materials used in the test article (highway appurtenance) fabrication or assembly that will be stressed to near yield or ultimate or that must fracture in a prescribed manner for proper impact behavior of the appurtenance shall be randomly sampled and tested to assure conformance with material specifications. Special processing of critical elements (such as heat treatment of metallic components) shall be denoted.

2. Erection

The test article shall be constructed and erected in a manner representative of installations in actual service and shall conform to the specifications and drawings of the

TABLE 1

RECOMMENDED SOIL * FOUNDATION FOR LONGITUDINAL BARRIER POSTS AND BREAKAWAY OR YIELDING SUPPORTS

U.S. BUR. OF STDS. SIEVE SIZE	RETAINED ON SIEVE (%)
1¾ in. (4.4 cm)	0
⅞ in. (2.2 cm)	10–35
⅜ in. (1.0 cm)	30–50
No. 4	45–65
No. 40	70–85
Maximum plastic index: 5	

* Crushed stone or broken gravel.

manufacturer or designer. To assure uniformity and integrity of structural connections, current American Welding Society specifications for highway bridges and American Institute of Steel Construction bolting procedures should be used. A deviation from fabrication, specification, or erection details shall be delineated in the test report.

B. Appurtenances

1. Longitudinal Barriers

For tests examining performance of the length-of-need section, the rails or barrier elements shall be installed straight and level and anchored. Horizontally curved installations, sloped shoulders, embankments, dikes, and curbs shall be avoided for general performance tests; when used, the nonstandard features shall be reported. Length of the test section excluding terminals shall 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 guardrail and median barriers. The type of end anchorages or terminals used shall be reported.

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

For tests of a transition joining two barrier systems, the more flexible system (in lateral direction) shall be installed in the upstream position. A minimum of 50 ft (15 m) of each of the two barrier systems shall be used.

2. Crash Cushions

A rigid, nonyielding backup structure (such as a concrete pier) shall be used to simulate a highway feature (such as a bridge pier, elevated gore, or bridge end) when appropriate. The crash cushion shall be anchored as required by specifications or drawings.

3. Breakaway and Yielding Supports

The breakaway or yielding segment shall 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. The supports shall be full-height structures, including sign, call box, or mast arm; an equivalent weight may be substituted for the luminaire.

IV. TEST VEHICLE

A. Condition

The vehicle shall be in good condition and free of major body damage and missing structural parts (i.e., doors, windshield, hood, etc.). 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 shall have a front-mounted engine, and the type and size of engine or transmission is unspecified. The vehicle bumper shall be standard equipment and unmodified for the test; its configuration and height above grade shall be reported. The model year of the test vehicle should be within four years of the year of test, with a maximum age of six years unless otherwise specified.

B. Mass

Vehicle mass is the gross mass of the car, ballast, and equipment at time of test and is specified in the appropriate test condition matrix. If required, ballast shall be contained within the passenger compartment and securely attached to the vehicle structure. When additional ballast is required, sandbags or dummies should be stationed in the four primary occupant positions and secured by lapbelts. With the exceptions of seats, spare tire, and optional equipment, components shall not be removed from the vehicle.

C. Speed and Braking

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

D. 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 impact.

V. TEST CONDITIONS

A. Test Matrix

The test article shall be evaluated for dynamic performance according to conditions specified in Table 2. The matrix of tests indicated for each appurtenance is considered a minimum; additional tests at other anticipated critical test conditions may be useful.

B. Vehicle Mass/Speed Adjustment

Vehicle mass is either 2,250 or 4,500 lb (1,020 or 2,040 kg) with an allowed variance of 200 lb (90 kg). To bring the vehicle mass within this range, ballast of up to 500 lb (225 kg) may be added to the vehicle. Although an impact speed is specified for the nominal vehicle mass, the impact speed shall be adjusted to maintain impact kinetic energy when the vehicle mass differs from the nominal.

C. Impact Points

For specific selection of impact points, the appurtenance shall be examined and impacted at the most vulnerable sites. Sites such as connections and potential snag points may be identified by visual inspection or review of drawings.

TABLE 2

CRASH TEST CONDITIONS FOR MINIMUM MATRIX

Appurtenance	Test Vehicle Mass,[d] lb (kg)	Speed mph (m/s)	Angle (deg)[e]	Target Vehicle Kinetic Energy[h] 1000 ft-lb (kJ)	Impact Point[k]
I. Longitudinal Barrier[(a)]					
A. Length-of-need					
Test 1	4500 (2040)	60 (26.8)	25[(f)]	540 ± 40 (733)	For post and beam system, midway between posts.
Test 2	2250 (1020)	60 (26.8)	15[(f)]	270 ± 20 (366)	Same as Test 1
B. Transition					
Test 1	4500 (2040)	60 (26.8)	25[(f)]	540 ± 40 (733)	15 ft (4.5 m) upstream of second system.
C. Terminal					
Test 1	4500 (2040)	60 (26.8)	0[(f)]	540 ± 40 (733)	Center of nose device.
Test 2	4500 (2040)	60 (26.8)	25[(f)]	540 ± 40 (733)	At beginning of length-of-need section.
Test 3	2250 (1020)	30 (13.4)	0[(f)]	68 ± 9 (92)	Center nose of device.
Test 4	2250 (1020)	60 (26.8)	15[(f)]	270 ± 20 (366)	Midway between nose and beginning of length-of-need.
II. Crash Cushions[(b)]					
Test 1	4500 (2040)	60 (26.8)	0[(g)]	540 ± 40 (733)	Center nose of device.
Test 2	2250 (1020)	60 (26.8)[(i)]	0[(g)]	270 ± 20 (366)	Center nose of device.
Test 3	4500 (2040)	60 (26.8)	20[(g)]	540 ± 40 (733)	Alongside, midlength.
Test 4	4500 (2040)	60 (26.8)	10-15[(g)]	540 ± 40 (733)	0-3 ft (0-1 m) offset from center of nose of the device.
III. Breakaway or Yielding Supports[(c)]					
Test 1	4500 (2040)	40 (17.9)	(j)	240 ± 25 (327)	
Test 2	2250 (1020)	20 (8.9)	(j)	30 ± 4 (40)	

Notes:

(a)Include guardrail, median barrier and bridge rail.
(b)Include devices such as water cells, sand containers, steel drums, etc.
(c)Include sign, luminaire, and signal box supports.
(d)±200 lb (90 kg).
(e)±2 degrees.
(f)From centerline of highway.
(g)From line of symmetry of device.
(h)Kinetic Energy (KE) = $(W/2g)V^2$ where W = vehicle mass in pounds and V is vehicle impact speed in fps.
(i)For devices that produce fairly constant or slowly varying vehicle deceleration; an additional test at 30 mph (13.4 m/s) or less is recommended for staged devices, those devices that produce a sequence of individual vehicle deceleration pulses (i.e., "lumpy" devece) and/or those devices comprised of massive components that are displaced during dynamic performance (see Commentary).
(j)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.
(k)Point on appurtenance where initial vehicle contact is made.

VI. DATA ACQUISITION SYSTEMS

A. Typical Parameters

Parameters to be measured before, during, and after impact are delineated in Table 3 together with measurement accuracies and techniques. Also given are optional parameters that may be monitored.

1. Pretest

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

2. Test

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

3. Posttest

After the test, the deformation and damage of both test article and vehicle shall be documented. Both Traffic Accident Scale (TAD) (*2*) and Vehicle Damage Index (VDI) (*3*) shall be determined.

TABLE 3

DATA ACQUISITION METHODS

Phase	Parameter	Measurement Accuracy	Acceptable Techniques	Remarks
Pretest	Test article installation	±0.02 ft (6.0 mm)	General surveying equipment. Photography.	Post spacing, rail heights, alignment, orientation, etc., are critical items.
	Vehicle mass	±20 lb (9 kg)	Commerical scales	Gross mass and distribution (four wheels) as tested.
Test	Impact speed*	±0.2 mph (0.09 m/s)	(a) Contact switches speed trap (b) High-speed cine (c) Radar (d) Fifth wheel	Minimum film speed of 250 fps.
	Vehicle accelerations	Longitudinal Barriers and Crash Cushions ±0.20 g Breakaway and Yielding Supports ±0.10 g	(a) Accelerometers	Lateral and longitudinal (and preferably 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 J211a Channel Class 60.
			(b) High-speed cine**	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 response (Optional)	±1.0 g's ±100 lb (45 kg)	Dummy	Anthropometric dummy, 50th percentile male, in driver position. Onboard camera with minimum film speed of 64 fps with view of subject from rear, over inside shoulder. Dummy should be restained by lap and shoulder belts. Dummy and belt restraints may be instrumented according to Federal Motor Vehicle Safety Standard 208.
	Test article dynamic strain (Optional)	±100 μin./in.	Resistance strain gage	System responsive to 0-min. 300 Hz. Data recorded by oscillograph or on magnetic tape.
	Test article dynamic deformation	±0.08 ft (24 mm)	High-speed cine	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		Visual inspection, VDI and TAD	TAD standard photographs should be shown in report.

*Speed measured during vehicle approach at a maximum 30 ft (9.1 m) from point of impact.

**To be used only as a backup or secondary system due to uncertainty in data processing attributed to a double differentiation calculation.

B. Additional Requirements

The parameters cited in paragraph VI.A.2 and the data acquisition systems shall not be considered inclusive. Other parameters peculiar to an appurtenance or to its expected application may entail additional techniques.

VII. PERFORMANCE EVALUATION

A. Appraisal Factors

Safety performance of highway appurtenances as evaluated for test conditions presented in Section V shall be appraised as to dynamic performance according to the recommended criteria given in Table 4. The three appraisal factors are (a) structural adequacy, (b) impact severity, and (c) vehicle trajectory hazard. Costs (i.e., installation, maintenance, damage repair, etc.), aesthetics, and other service requirements are not evaluated.

B. Structural Adequacy

The appurtenance shall perform successfully according to all requirements of *structural adequacy* (Table 4). 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. Moreover, the appurtenance shall remain essentially intact during collision without fragmenting into debris that could penetrate the passenger compartment or present undue hazard to other traffic.

C. Impact Severity

A number of factors (such as vehicle compartment geometry, padding, and occupant restraints) are outside the control of highway engineers. To remove the variability of these factors from appurtenance design, impact severity is appraised according to either vehicle accelerations or momentum 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 impact severity criteria (Table 4) shall 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. If the optional use of anthropometric dummies is exercised, the dummies shall be fully restrained by both lap and shoulder belts to minimize their interactions with the passenger compartment interior; it is suggested that procedures and evaluation criteria of FMVSS 208 (*5*) be used, although highway appurtenance crash testing is beyond the stated purpose of FMVSS 208.

D. Vehicle Trajectory Hazard

Vehicle trajectory hazard (Table 4) is a measure of the potential of a redirected car causing a subsequent multivehicle collision; this is an important consideration for appurtenances at high-density traffic locations. It is preferred for the vehicle to remain near the installation and away from other traffic. A subjective appraisal shall be made by the test engineer as to the trajectory hazard, based on vehicle exit speed and angle, maximum intrusion into a traffic lane or lanes during trajectory, and postcrash controllability of the vehicle.

VIII. REPORT

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

A. Appurtenance Description

The test article shall be fully described, with engineering drawings and material specification. Reference shall 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 and weldments) that may influence the dynamic behavior.

B. Test Procedures

A complete description of the test facility and associated equipment shall be contained in the report. When appropriate, soil properties and conditions shall be reported. The data acquisition systems shall be fully described, together with the procedures used in calibrating and processing the data.

C. Findings

To facilitate comparison of findings from two or more testing agencies, a findings presentation format as shown in Table 5 is recommended. As a part of the report, a 16-mm color movie shall 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.

D. Evaluation

The dynamic performance of the test article shall be discussed with regard to the three evaluation factors: structural adequacy, impact severity, and vehicle trajectory hazard. A conclusion may be presented as to acceptability of the dynamic performance of the appurtenance. Recommendations may be offered as to modifications that may improve the article and to situations where the article may be applicable.

TABLE 4

SAFETY EVALUATION GUIDELINES

Dynamic Performance Factors	Evaluation Criteria	Applicable Criteria for Appurtenance			
		Longitudinal Barriers		Crash Cushions	Breakaway or Yielding Supports
		Length-of-Need and Transitions	Terminals		
I. Structural Adequacy	A. The test article shall redirect the vehicle; hence, the vehicle shall not penetrate or vault over the installation.	●			
	B. The test article shall not pocket or snag the vehicle causing abrupt deceleration or spinout or shall not cause the vehicle to rollover. The vehicle shall remain upright during and after impact although moderate roll and pitching is acceptable. There shall be no loose elements, fragments or other debris that could penetrate the passenger compartment or present undue hazard to other traffic.	●	●	●	●
	C. Acceptable test article performance may be by redirection, containment, or controlled penetration by the vehicle.		●	●	
	D. The terminal shall develop tensile and/or flexural strength of the length-of-need.		●		
II. Impact Severity (See Section VII of Commentary for discussion and limitation of guide-line values)	A. Where test article functions by *redirecting* vehicle, maximum vehicle acceleration (50 msec avg) measured near the center of mass should be less than the following values: Maximum Vehicle Accelerations (g's) Lateral / Longitudinal / Total / Remarks 3 / 5 / 6 / Preferred 5 / 10 / 12 / Acceptable These rigid body accelerations apply to impact tests at 15 deg or less.	●	●	●	
	B. (Optional). Anthropometric dummy responses should be less than those specified by FMVSS 208 (e.g., resultant chest acceleration of 60 g, Head Injury Criterion of 1000, 1800 lb (8 kN) shoulder harness and 5000 lb (22.2 kN) total lap belt).	○	○	○	○
	C. For direct-on impacts of test article, where vehicle is decelerated to a stop and where lateral accelerations are minimum, the maximum average permissible vehicle deceleration is 12 g as calculated from vehicle impact speed and passenger compartment stopping distance.		●	●	
	D. Maximum momentum change of the vehicle during impact shall be 1100 lb-s (4892 Ns). This is required for Test 1 only; preferably it is applicable to both Tests 1 and 2.				●
III. Vehicle Trajectory Hazard	A. After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes.	●	●	●	●
	B. Vehicle trajectory behind the terminal is acceptable.		●		

TABLE 5

FINDINGS FORMAT

Item	Description	Format	Scale (units/in.)	
			Ordinate	Abscissa
Photography Still Movie	 Before and after test of vehicle and installation Sequence (4 to 8 frames) during impact	 Photographs Photographs		
Acceleration Vehicle Dummy(1)	 Lateral and longitudinal; filtered (see Sec. VI) Chest and head x, y, and z; filtered (SAE J211a)	 Plots(2) Plots	 10 g(3) 20 g	 100 ms 100 ms
Seat Belt Force(1)	Lap and shoulder harness	Plots	1000 lb (453 kg)	100 ms
Dynamic Strain(1)	Strain gage data from critical appurtenance points Drawing showing strain gage locations	Plots Drawing	500 μin./in.	100 ms
Deformation Permanent Dynamic	 Profile of deformation Maximum deformation of test article	 Table 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:

(1)Optional.

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

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

PART II. COMMENTARY

I. SCOPE

Purpose

The primary purpose of the recommended procedures is to promote uniform testing practices whereby highway design engineers may have a basis for comparing the relative merits of two or more candidate appurtenances based on test results. The highway designer should be aware that vehicle crash testing is a method for developing and screening new appurtenances and that the final merit of an appurtenance must be based on in-service performance.

Vehicle crash tests are complex experiments and are difficult to replicate due to 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 at the same time maintaining their costs within acceptable bounds. The highway engineer should recognize the limitations of these tests and exercise care in interpreting the results.

The testing procedures are devised to subject highway appurtenances to severe or worst conditions rather than to "typical" or the more predominant highway situations. By use of this approach, which was first advanced by procedures of *HRB Circular 482* [4,000-lb (1,814 kg) car, 60 mph (26.8 m/s), 25 deg] (*1*), longitudinal barriers have been developed that function acceptably over a wide range of impact conditions that encompass most of the present highway traffic. Barriers developed under this somewhat conservative approach are only marginally more expensive than those that will perform under less severe [i.e., 4,000-lb (1,814 kg) car, 60 mph (26.8 m/s), 15 deg] 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; an idealized soil is specified, although guardrails are often installed in poor soil or frozen ground. These normalized factors have significant effect on a barrier's performance, but become secondary in importance when comparing 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. Obviously, when the highway engineer requires the performance of a system for specified site conditions (such as a unique soil or curb layout) these conditions should be used instead of the idealized conditions.

The procedures are intended for use with passenger vehicles in the mass range of 2,050 to 4,700 pounds (930 to 2,131 kg). Because there is limited experience on which to base testing procedures, testing with large and articulated vehicles is beyond the scope of this document. However, researchers and testing agencies performing large-vehicle tests are encouraged to follow these procedures when appropriate and to report deviations.

These procedures are not intended to replace other type tests (such as those performed in a pendulum facility). Procedures for performing other types of appurtenance tests are beyond the scope of this document.

Definitions

Longitudinal (*6*) traffic barriers are devices that perform by redirecting errant vehicles away from roadside hazards; examples of longitudinal barriers are guardrail, bridge rail, and median barrier installations. Elements of a typical longitudinal barrier are length-of-need, terminals, and transitions. The length-of-need segment (or midsegment of a longitudinal barrier) is established such that practically all errant vehicles that may strike the hazard being shielded are intercepted. Upstream and downstream terminals develop the redirective properties 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 (i.e., cable to W-beam or W-beam to concrete rail); 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 (*6*), also called impact attenuators, have a prime purpose of safely stopping errant vehicles. A crash cushion 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 (*7*) 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.

II. 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 recommended soil is a well-graded gravel material that should be readily available to most testing agencies. The low-cohesive 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.

A structure simulating a bridge is suggested for bridge rail tests for two reasons. First, forces induced in the bridge structure during impact can be measured; second, the vehicle trajectory during redirection can be monitored to observe if a wheel drops below deck level and is trapped.

III. TEST ARTICLE

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.

Materials of most concern are those that are highly stressed (such as 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. It should be noted that well-defined material specifications and appropriate fracture modes are not developed at this time for the specific appurtenance in this report.

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.

For breakaway and yielding appurtenances, the detached elements represent a potential hazard to other traffic; consequently, the full-height structure shall 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.

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 (*7*).

Displacement and/or rotation of the footing during vehicle impact with a breakaway device may adversely affect the fracture mechanism. Inspection of in-service breakaway structures has revealed foundation or soil conditions that do not properly fix the breakaway device. In recognizing that the breakaway device and footing must function as a system, the procedures specify that the appurtenance details include the footing structure. Fixity of the breakaway device is provided by footing inertia (mass) and passive soil resistance. The footing for use in testing a breakaway device should be designed for minimum wind conditions, thus yielding a minimum footing mass and size; a larger footing will yield a greater breakaway device fixity and, hence, is less critical. The soil should be compacted around the footing, thus assuring full passive soil resistance; 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.

Conditions for testing crash cushions should be in keeping with expected use of the device. That is, the cushion may require validation for side redirection as well as for end-on impacts. However, certain devices have no redirective capability, hence only the end-on deceleration feature is of interest (i.e., dragnet). 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.

IV. TEST VEHICLE

Vehicle design and its condition at the time of test can have major influence on the dynamic performance of an appurtenance. Vehicle bumper height, configuration, and stiffness; vehicle mass distribution and suspension system; and vehicle structure, are the more important parameters. In establishing the recommended procedures, consideration was given to specifying a standard bogie or to selecting a specific make and model of domestic car as the test vehicle. However, the concept of using late-model passenger vehicles without specifying manufacturer is used because it provides for the more general evaluation of an appurtenance; otherwise, appurtenances could be developed that are singularly tuned to a bogie or a standard test car. It is conjectured that current automobile design trends to standardize bumper height and impact performance and to improve general crashworthiness of the car will decrease the wide range of dynamic performance among various vehicles when interacted with a highway appurtenance.

The test vehicle should be in sound structural shape without major sheet metal damage. Use of a vehicle for more than one crash test should be avoided, as 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.

Two vehicle sizes are suggested by mass: a standard-size sedan [4,500 lb (2,040 kg)] and a subcompact [2,250 lb (1,020 kg)]. To adjust a test vehicle mass within the allowable 200-lb (90 kg) variance of these target values, a ballast of 500 lb (225 kg) may be added to the car. The added ballast may be thought of as four 125-lb (57 kg) passengers. To minimize any unusual changes in the vehicle weight distribution and mass moments of inertia, the ballast should be contained within the passenger compartment and around the center-of-mass and should be securely attached to the vehicle structure. Sandbags or dummies, stationed in the four primary occupant positions and secured with lapbelts, would satisfy these requirements.

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

Because vehicle front wheels frequently 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 posttest trajectory. For this reason, braking should be delayed as long as safely feasible so that the unbraked posttest trajectory can be observed.

V. TEST CONDITIONS

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

The number of tests recommended for each appurtenance should be considered a minimum. Additional tests at other impact conditions are suggested to further establish performance of an appurtenance. Specific impact conditions should be devised in order that potentially critical elements of a test article are examined; generally, it is anticipated that impact conditions of the additional tests will be within the range of conditions of the recommended tests.

Vehicle kinetic energy at impact is presented as a test control

$$\text{K.E.} = \frac{W}{2g} V^2 \qquad (1)$$

in which W is vehicle mass in pounds, and V is vehicle speed in fps. As a 200-lb (90 kg) variance in test vehicle mass is permitted, it is recommended that the target impact speed be adjusted to attain the suggested kinetic energy level. For example, a test vehicle mass with the maximum allowable 500-lb (225 kg) ballast is 4,300 lb (1,950 kg) instead of 4,500 lb (2,040 kg); to attain the 540,000-ft-lb (733 kJ) kinetic energy level, the vehicle speed should be targeted at 61.4 (27.4 m/s) instead of 60 mph (26.8 m/s). In a similar manner, if the vehicle mass is 4,700 lb (2,131 kg), the target impact speed should be reduced from 60 (26.8 m/s) to 58.7 mph (26.2 m/s).

Longitudinal Barriers

Test 1 [i.e., 4,500-lb (2,040 kg) vehicle/60 mph (26.8 m/s)/25 deg] should be considered primarily a strength test of the installation in preventing the vehicle from penetrating or vaulting. The 25-deg approach angle is severe when compared to findings of Hutchinson (*8*) that show that 75 percent of vehicles leave the pavement at 15 deg or less. In contrast, California Department of Transportation (*9*) reports that about 50 percent of the vehicles in an accident study in the Los Angeles area struck the barrier at 15 deg or more. Based on experience of systems evaluated at the *Circular 482* (*1*) criteria, the systems perform well in service under a wide range of layout conditions and road alignments. Test 1 should be considered principally a strength test, and evaluation of vehicle redirection severity as related to vehicle occupants is somewhat of a secondary consideration. Nevertheless, vehicle decelerations should be measured and reported.

Conditions for Test 2 were established based on the following factors:

1. The population of small cars is increasing. With other factors being equal, the redirection of a small car impacting a system where stiffness is dependent on deformed shape alone will be more severe than for a large car. Also, the small car has a shorter wheelbase and a narrower track, making it more vulnerable to rollover during redirection.
2. The 60-mph (26.8 m/s) and 15-deg impact represent an appropriately severe test for measuring redirection performance of the test article in terms of vehicle decelerations and vehicle damage.

The vehicle should be in a driveable condition after Test 2.

Only one test is suggested for evaluating transitions between longitudinal barriers of different lateral flexibility. Because the transition normally will be situated in a length-of-need, it should be evaluated according to the length-of-need strength test. The principal failure mode is for the vehicle to pocket or snag, with this occurring at transitions from flexible to rigid systems. Transitions from rigid to flexible systems are believed to be noncritical.

Terminals should be evaluated for (1) end-on hits for large and small cars (Tests 1 and 3, respectively), (2) adequacy of the anchorage at the beginning of the length-of-need (Test 2), and (3) the redirective performance midpoint between the nose and the beginning of the length-of-need (Test 4); four tests are suggested. 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 two vehicle sizes and two impact kinetic energy levels. The adequacy of the terminal anchorage function is demonstrated using Test 2. 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 behavior of a vehicle striking within the terminal is demonstrated using Test 4; acceptable performance is by either redirection or controlled penetration by the vehicle.

The test matrix for the longitudinal barrier is formulated mainly for high-speed conditions existing on primary highways. Whereas traffic speed may be lower for secondary highways and departure angles of vehicles leaving the pavement less for these narrow dual-lane roads, the actual impact conditions may be similar to primary highways due to less stringent highway alignment requirements for secondary roads. For this reason, unless a study indicates that other procedures should be followed, it is suggested that barrier systems installed on primary or secondary highways should be evaluated for similar impact conditions.

Crash Cushions

Similar to a longitudinal barrier terminal, a crash cushion is expected to perform for a wide range of 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 (*10*) with the first-generation crash cushion designs, a minimum matrix of four tests has been devised that examine and demonstrate a device at four 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 (26.8 m/s), 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 110 percent of the posted speed limit for the four tests instead of 60 mph (26.8 m/s).

Four tests are recommended for evaluating a crash cushion:

- Test 1: [4,500-lb (2,040 kg) vehicle/60 mph (26.8 m/s)/0 deg into center nose of the device]. The objective of this test is to evaluate the energy-absorbing/dissipation property of the test article for a severe set of impact conditions. Vehicle stability and deceleration intensity are chief concern.
- Test 2: [2,250-lb (1,020 kg) vehicle/60 mph (26.8 m/s)/0 deg into center nose of the device]. The primary purpose of this test is to demonstrate that vehicle deceleration, which is generally critical for the small car, 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 [2,250-lb (1,020 kg) vehicle/30 mph (13.4 m/s) or less/0 deg into the center nose of the device] 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 is considered more critical due to the relatively high initiation force required to mobilize such crash cushions—that is, cushions consisting of a field of timber posts or individual fragmenting structures.
- Test 3: [4,500-lb (2,040 kg) vehicle/60 mph (26.8 m/s)/20 deg alongside of crash cushion]. This test is to evaluate crash cushions for redirectional performance capability. It is desirable to have crash cushions that will perform at 60 mph (26.8 m/s) and 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 a minimum test criterion where redirectional performance is evaluated. The point of impact should be approximately at midlength 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.
- Test 4: [4,500-lb (2,040 kg) vehicle/60 mph (26.8 m/s)/10-15 deg impact angle/0-3 ft off-center from point of nose]. 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 1, 2, and 3 have been used in developing first-generation crash cushions, Test 4 is a new test and should provide 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

Two tests are suggested for this type of highway appurtenance—a 4,500-lb (2,040 kg) (Test 1) and a 2,250-lb (1,020 kg) (Test 2) vehicle impacting the test article at 40 (17.9) and 20 mph (8.9 m/s), respectively. The purposes of conducting Test 1 are to evaluate the maximum deceleration or velocity change of the vehicle and to evaluate the trajectory and final resting place of any detached elements (such as luminaire poles) with respect to other traffic. Test 1 has been used for several years, and a significant number of test results have been accumulated.

Test 2 is a new test, and it is unknown whether current-generation breakaway or yielding supports can meet the 1,100-lb-sec (4,892 Ns) momentum change criterion for the specified impact conditions. For this reason, the objective of the test is to demonstrate that the support will activate or fracture in the designed manner. Although the 1,100-lb-sec (4,892 Ns) momentum change criterion is not presently applicable to Test 2, it is a worthy design goal for breakaway and yielding supports; the momentum change should be reported. Although pendulum test procedures are being investigated by FHWA for possible upgrading, Test 2 conditions approximate present pendulum impact values [i.e., 2,000 lb (907 kg) mass and 20 mph (8.9 m/s]; hence, Test 2 may provide the necessary correlation data to verify the usefulness of the less costly laboratory test.

The impact point should be centered on the vehicle bumper. Multiple tests with the same vehicle in which vehicle bumper or front-end crush properties are changed shall be aovided.

Although a number of accidents have been reported where a breakaway device failed to function when struck broadside by a vehicle, there are no recommendations for the side impact test. Research is currently under way by others to explore and possibly define such a test.

VI. DATA ACQUISITION SYSTEMS

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 and collision debris. Hence, data acquisition systems are specified to document the dynamics of the vehicle and test article during and immediately after impact.

The limits of measurement precision given in Table 3 were established based on two factors: the minimum variation in the parameters of current or near-future significance, and economical and technical feasibility. Precisions 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 precision would permit a tolerance of 5 g's for a 500-g accelerometer; this excessive tolerance could obscure significant vehicle response, which generally ranges below 15 g.

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 J211a Channel Class 60 for reporting. Hence, the broadband data may be filtered to other channel class requirements to meet future needs.

The complete accelerometer data acquisition system should be calibrated against a known standard as suggested in SAE J211a (*4*). 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. A posttest calibration of the complete accelerometer system should be performed to ascertain operational status of the system and identify possible measurement problems.

Mounting on 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 vehicle "B" pillars with a rigid steel beam (i.e., 10 plf or greater) and then attach the accelerometer block to the beam.

The sign convention for vehicle positive accelerations is shown in Figure 1. 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.

A discussion of the application of strain gauges is beyond the scope of this document. A most complete presentation of strain gauge technology has been compiled by Murray and Stein (*16*). Calibration procedures on bonded strain gauges are presented in ASTM E251-67 (*17*).

Use of anthropometric dummies is considered optional for current evaluation of highway appurtenances. However, the testing agency is encouraged to use the device or devices. In the event that fully instrumented dummies are employed, it is recommended that the devices be restrained by both lap and shoulder belts. Whereas the full restraint requirement is in conflict with current public use factors, this idealized condition is readily achieved, and it greatly reduces the interaction of the dummy and the compartment interior of the vehicle. Hence, the dummy responses are more a function of vehicle accelerations and restraint system and less a function of vehicle interior geometry and padding. Instead of using instrumented dummies, at least two testing agencies have used devices restrained only by lap belts and have monitored the gross movements with rear seat cameras.

Because of an occasional malfunction of the data acquisition system, it is recommended that independent backup systems be used for monitoring vehicle impact speed and accelerations.

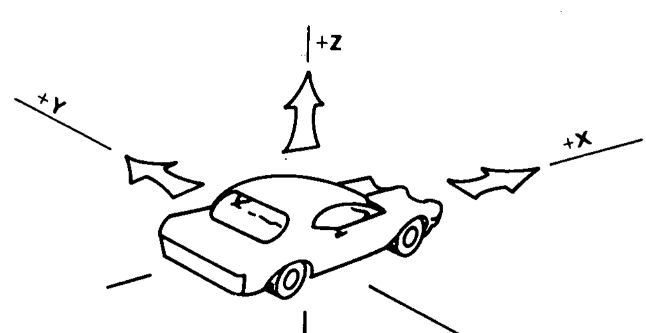

Figure 1. Vehicle accelerations sign convention.

VII. PERFORMANCE EVALUATION

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 merit of two or more promising candidate appurtenances, the test results should not be used to project the performance of an appurtenance for in-service use or in a hypothetical 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 over-all performance of an appurtenance; guidelines for these two factors are beyond the scope of this document.

In-service experience has indicated that vehicle collisions with even the best highway appurtenance have resulted in injuries and fatalities. Accordingly, placement of an appurtenance close to the pavement [say 30 ft (9.1 m)] 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 roadside hazard; or (2) the benefit of an appurtenance (such as lighting or signing) in reducing the number of injury and fatality accidents.

Evaluation criteria are presented for three interrelated factors: structural adequacy, impact severity, and vehicle trajectory hazard. For structural adequacy, the appurtenance should perform its function of redirecting, containing, or permitting controlled penetration of the test vehicle in a predictable and safe manner. This implies that the vehicle remains relatively upright throughout impact, without excessive rolling or pitching, and is smoothly redirected or decelerated. Also, the collision debris from the appurtenance should not present an undue hazard to the passengers or to other traffic.

Impact severity is evaluated according to vehicle responses of accelerations and change in momentum. This presumes that there is a relationship between vehicle dynamics and occupant safety. This relationship is tenuous, as 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 deceleration pulse while restrained with lap and shoulder belts) (*11, 12*). Although findings from these efforts serve as a benchmark, they are not directly applicable to the complex highway collision.

The guidelines for impact severity presented in Table 4 have evolved from several sources during the past 10 years (*13*). 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 and numerically averaged over the designated time base. For example, accelerations from a redirected vehicle should be processed by a SAE J211a Channel Class 60 device and then the signal should be examined for the maximum 50-ms average; using a time base longer than 50 ms eliminates effects of frequencies as low as 20 Hz from the signal and attenuates the maximum value.

It should be noted that the recommendation given in Section II.A. of Table 4 concerning acceleration levels computed by 50-ms average for 15-degree impacts on longitudinal barriers is a new guideline, as almost all tests to date have been conducted at 25 degrees. Thus, it is not known at this time if all tested traffic railings now in use for new construction would meet the guidelines given in this table.

Appurtenances that are designed to stop the vehicle are evaluated on the basis of a computed average deceleration. Currently, two different methods are available for computing the average deceleration: the first is based on vehicle impact speed and stopping distance measured at the passenger compartment; the second averages the filtered vehicle acceleration record over the highest 50-ms interval. At present there is no concensus as to which of these two methods gives a better correlation with occupant injury probability. It is expected that every effort will be made in design to ensure that deceleration is fairly uniform over the entire event. If this is the case, there should be no significant difference in the results from either method. There may be cases in which the deceleration signal is not fairly constant (e.g., impact involving an array of wooden posts). In such cases the maximum-50-ms method gives a more conservative result and is recommended. The desirable level of average acceleration is from 6 to 8 g's, which was shown to be obtainable in several available crash cushion and longitudinal barrier terminal designs. In all cases, however, the average acceleration shall be limited to 12 g's; existing evidence indicates that some injuries can be expected at this deceleration level but most of these will not be fatal. To aid in comparison of test results, the average acceleration values from both of the foregoing methods and the filtered acceleration signal should be reported for all cases.

The "maximum change in momentum" criterion of 1,100 lb-sec (4,892 Ns) was developed for breakaway supports (*15*); a lower limit of 750 lb-sec (3,335 Ns), is preferred and is a desirable goal for new devices, although the higher limit is acceptable. For yielding supports (such as base-bending signs) change in vehicle momentum to be used in the acceptance criteria of this section shall be computed on the basis of time integration of the vehicle deceleration signal over a "duration of the event." This duration shall be defined as the lesser of the following: (1) time between incipient contact and loss of contact between the vehicle and the yielding support, or (2) the time for a free missile to travel a distance of 24 in. starting from rest with the same magnitude of vehicle deceleration.

Vehicle trajectory hazard is a concern as it relates to other traffic. Obviously, it is preferable to confine the ran-off-the-road incident to the errant vehicle without involving innocent traffic. A vehicle that is abruptly redirected back into the traffic stream poses a panic situation that may initiate subsequent multicar collisions. Although there are numerous reported collisions caused by the redirected vehicle, the significance of this performance factor with respect to other appurtenance performance factors is unknown because of incomplete accident data and analysis. In addition, test vehicle postcrash trajectory has been one of the least repeatable performance factors because of the random nature of damage to vehicle suspension, tires, etc., which greatly alters the vehicle stability and path. Moreover, because driver response in avoiding secondary collisions is not simulated in the crash tests, it is inappropriate to predict in-service performance based on the test trajectory. Hence, for the present, the highway engineer should strive for appurtenance designs that provide for minimum vehicle postcrash trajectory interference with other traffic while maintaining acceptable structural adequacy and impact severity values.

VIII. 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 2, includes major elements of a report.

In presenting findings, at least two 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 3.

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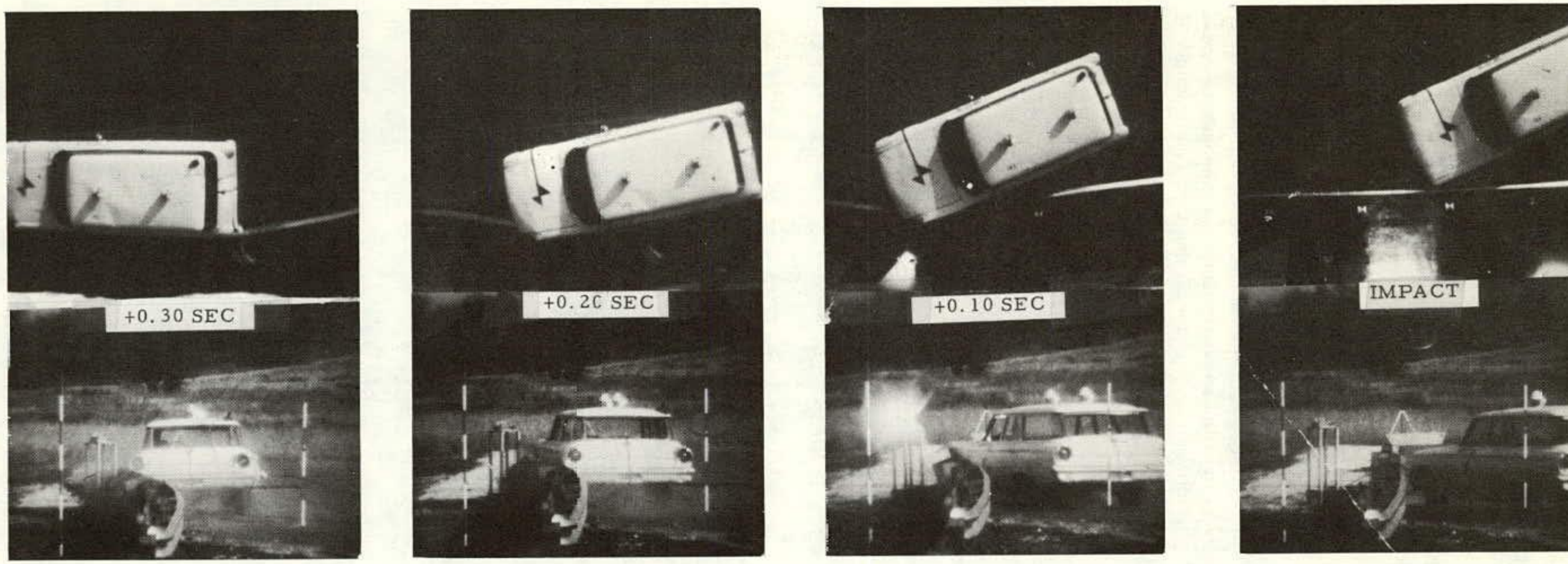
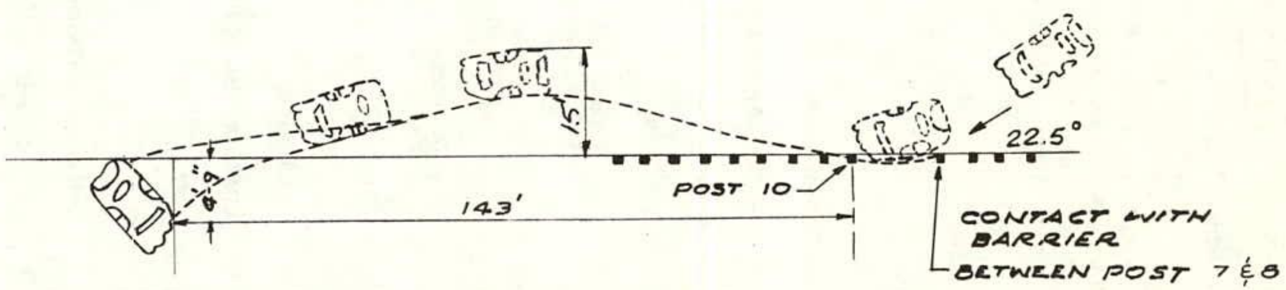
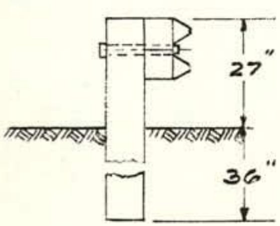
Figure 2. Example table of contents.







California Blocked-Out "W"-Beam

Test No.	SwRI 103
Date	12/19/68
Drawing	SwRI 2176-01
Beam Rail	12-ga Steel x 12.5 ft (3.8 m)
Post	8 x 8 in. (20 x 20 cm) S4S SYP x 5.33 ft (1.6 m)
Post Embedment	36 in. (0.9 m)
Post Spacing	6.25 ft (1.9 m)
Length of Installation	100 ft (30 m)
Ground Conditions	Dry
Beam Rail Deflection	
Max. Dynamic	2.8 ft (0.85 m)
Max. Permanent	2.4 ft (0.73 m)

Vehicle	1963 Ford Country Sedan
Vehicle Mass (w/dummy & instrumentation)	4120 lb (1868 kg)
Dummy Restraint	Lap & Shoulder Belts
Impact Speed	60.1 mph (26.9 m/s)
Impact Angle	22.2 deg
Exit Angle	15 deg
Vehicle Accel (max. 50 ms avg)	
Lateral	-6.5 g
Longitudinal	-3.2 g
Vertical	-
Vehicle Rebound Distance	15 ft (4.6 m)
Vehicle Damage	
TAD	11 RFQ 3
VDI	11 YEW 4

Figure 3. Summary of results, full-scale crash test 103.

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