TRANSPORTATION RESEARCH

CIRCULAR

Number 374, July 1991

Update of NCHRP Report 230

Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances

TRANSPORTATION RESEARCH BOARD / NATIONAL RESEARCH COUNCIL

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CIRCULAR

Number 374, July 1991
ISSN 0097-8515

UPDATE OF NCHRP REPORT 230
Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances

TRB Group 2 - Design and Construction of Transportation Facilities
SECTION A - General Design
Committee A2A04, Roadside Safety Features - Members, 1988

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IIA highway and facility design

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Preface

This circular contains the proceedings of a workshop sponsored by TRB Committee A2A04, Roadside Safety Features, held at Sacramento, California, August 15-16, 1988. The proceedings include the written version of eight presentations on various update topics, a list of discussion topic questions, the summaries of discussions by four break-out groups as presented by the discussion group leaders, and a prioritization of 15 potential update study topics by workshop attendees.

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PART 1 INTRODUCTION

Virtually all new or modified roadside safety devices in this country are crash tested in accordance with the guidelines in National Cooperative Highway Research Program (NCHRP) Report 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," which was published in March 1981. Comprehensive crash test guidelines were first published in 1974 as NCHRP Report 153, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," and were modified slightly in Transportation Research Circular No. 191 in 1978. Thus, NCHRP Report 230 was the first major revision of the original crash test guidelines. It added tests with lighter weight cars (1800 lbs.), optional tests with buses and trucks, a new method of evaluating the risk to occupants, and a section on in-service evaluation and numerous other refinements. It was a consensus document that was comprehensively reviewed by all members of the roadside safety hardware community, and it was intended to reflect the state of the art as well as to forecast needs in the near future.

Since 1981 there have been many changes in this field necessitating an update in NCHRP Report 230. AASHTO approved a new NCHRP research project in late 1987 for this purpose. Project 22-7 was titled "Update of 'Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances.'" Excerpts from the Project Statement follow:

Research Problem Statement

NCHRP Report 230, 'Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances,' published in March 1981, contains a compilation of recommended procedures for evaluating the safety performance of highway appurtenances. These recommendations were based on a synthesis of information found in the literature and a state-of-the-art survey, and on advice obtained from a selected group of acknowledged experts. Since its publication, NCHRP Report 230 has served as the generally accepted guide for developing and evaluating highway safety hardware. However, the characteristics of the vehicles on our roadways have changed substantially since 1981; safety appurtenances not considered in that report have come into use, and research efforts using full-scale crash tests, bogie and pendulum tests, computer simulations, and traffic accident analyses have resulted in improved understanding of vehicle interactions with highway appurtenances and roadside terrain. In addition, performance levels other than those included in NCHRP Report 230 are being considered for use. On the basis of these changes, an update of NCHRP Report 230 is needed at this time to ensure continued improvement in the level of safety provided users of the highway system.

Objective

The objective of NCHRP Project 22-7 is to update the recommended procedures for the safety performance evaluation of both temporary and permanent highway appurtenances in such a manner as to reflect advances in technology and to accommodate current and anticipated roadway and vehicle characteristics.

This project will consist of two phases to be performed consecutively, with a review required at the completion of Phase I on which authorization to proceed with Phase II will be based. Proposals covered both phases of the study and included at least the following tasks:

Phase I

Task 1. Develop a comprehensive list of topics to be examined in updating the recommended procedures. This list shall be based on a critical review of past and on-going research, and input from knowledgeable individuals involved with and interested in the subject area.

Task 2. Evaluate the relative importance of each of the topics cited in Task 1 and identify important issues within each topic.

Task 3. Prepare an interim report documenting the efforts completed in Tasks 1 and 2. The interim report shall also include an annotated outline of the final report and a detailed work plan describing the activities required in Phase II. Submit the interim report to the NCHRP Project Panel for review and approval. A meeting between the research team and the NCHRP Project Panel will be planned at the completion of Task 3 to discuss the results of Phase I and the work planned for Phase II. The investigators shall prepare a revised interim report to reflect the outcome of the meeting and distribute it to the project panel members.

Phase II

Task 4. Using the information generated in Phase I, prepare a first draft of the final report and document, under separate cover, how each of the issues identified was resolved. The investigators shall also prepare a proposed list of reviewers from the highway community-at-large for approval by the panel. A second meeting between the research team and the project panel will be planned at the completion of task 4 to discuss the first draft of the final report, the list of issues identified and how they were resolved, and the proposed list of reviewers. The investigators shall prepare a second draft of the final report to reflect the outcome of the second meeting and distribute the revised document to the project panel members and to the reviewers approved by the project panel in this task.

Task 5. Evaluate the reviewers' comments and prepare a brief discussion of the comments and their disposition. Based on the results of this effort, prepare a third draft of the final report. A third meeting between the researchers and the NCHRP Project Panel will be scheduled at the completion of Task 5 to discuss the comments received from the community-at-large, the disposition of those comments, and the third draft of the final report.

Task 6. A final report shall be prepared based on the outcome of the third meeting between the researchers and the NCHRP Project Panel."

The first two panel meetings for NCHRP Project 22-7 were held in spring and summer of 1988 to select a contractor. Funding was allocated and the project officially began in June 1989 at the Texas Transportation Institute.

TRB Committee A2A04 decided that the theme of their 1988 Summer Workshop should be this NCHRP Project to update Report 230. It was hoped that this workshop would mobilize the roadside safety hardware community before the project began to think intensely about and formulate agendas. Thus, the contractor could begin the project with a substantial input from a majority of safety community members knowing the approximate state of the art and the current philosophies and concerns of each one. Fortunately, there was a good representation of the community attending from government, industry, academia, etc., 44 in all. They included members of TRB Committee A2A04 and other members of the roadside safety feature community. A list of attendees is given in Appendix B. The remainder of the Circular describes the proceedings at the 1988 summer workshop.

The welcome handout included the following general ideas to keep in mind during the workshop:

1. The ultimate goal of the crash test guidelines is to save lives and reduce the severity of injuries in accidents where vehicles leave the roadway out of control.

2. The new guidelines will not be published before mid-year 1991. Research and testing studies begun after the guidelines are published may not be completed for one to three or more years. New safety devices qualified for use under the new guidelines may not actually be installed in large quantities until a few years later, preferably only after trial installations of one to two years. Hence, the effect of the new guidelines may not be evident until almost the year 2000. Consequently, this long delay requires careful thinking about the needs of the future.

3. The desire for maximum safety must be tempered with a careful analysis of the real world which includes political and economic factors. Transportation funding is scarce.

4. The guidelines should be as short and simple as possible, and should represent a consensus of the highway safety community as much as possible in order to promote widespread use and strict adherence to all provisions.

The workshop agenda is given in Figure 1 and focused on three main parts. The first morning, the group heard eight presentations on various update issues. These were intended to present strong points of view by the authors about possible update changes and to provoke discussion. The first afternoon the group split into four break-out discussion groups and used handout discussion topics to draw out opinions from those in each group. The groups were formed so as to mix representatives of government, industry, etc., in order to get a variety of viewpoints. The second morning the four discussion group leaders reported on the ideas presented in their groups with some attempts to judge the importance of various issues. Finally, all attendees ranked a list of 15 major issues, and the results were tallied and reported.

Figure 1 Agenda

Monday, August 15, 1988

8:00 a.m. Late registration

8:30 a.m. Welcome, Introductions and Announcements
Charles Bartell
Bill Hunter
Roger Stoughton

9:00 a.m. Background Issues Pertinent to NCHRP 230

Assessing and Refining the Purpose of NCHRP 230
Charles Bartell, Caltrans

The Test Matrix
Jim Hatton, FHWA

Refining Crash Test Assessment Procedures and Criteria
Dean Sicking, TTI

Review of Biomechanical Impact Response and Injury in the Automotive Environment
John Melvin, General Motors

10:00 a.m. Break

10:30 a.m. Continue with Speakers

Examining the Control of Crash Test Conditions
King Mak, TTI

Using Surrogate Test Vehicles, Computer Simulations, and Other Alternative Procedures
Marty Hargrave, FHWA

In-Service Evaluation
Dave Woodham, Colorado Department of Highways

The Industry Perspective of NCHRP 230
Owen Denman, Energy Absorption Systems, Inc.

11:30 a.m. Breakout Session Instructions

11:45 a.m. Lunch

1:00 p.m. Breakout Sessions

3:00 p.m. Break

5:00 p.m. Recess

6:30 p.m. Dinner

Tuesday, August 16, 1988

8:30 a.m. Presentation of Breakout Session Results
Floor Discussions - Questions and Answers

Prioritize Major Issues

10:00 a.m. Break

10:30 a.m. Report Tally of Priorities from Workshop Participants

11:30 a.m. Other Committee Business

12:00 Noon Adjourn

PART 2 PRESENTATIONS: BACKGROUND ISSUES PERTINENT TO NCHRP REPORT 230

A. The Purpose of the NCHRP Report 230 Update

***By*: Charles Bartell, California Department of Transportation**

The original intent of NCHRP Report 230 and its predecessors was to provide recommended uniform procedures for conducting full-scale crash testing of highway safety appurtenances and evaluating the data from these tests. This was to permit comparison of different candidate appurtenances based on full-scale tests, often by different testing organizations. The necessity of rerunning a series of tests to slightly different criteria for different highway agencies was eliminated.

Most of the original requirements for test conditions and matrices evolved from research performed in developing roadside barriers, that is guardrail, median barrier, and bridge railing. Uniform test and evaluation procedures of various designs and their modifications were to be compared, even when some of the tests were performed by others. Over the years it has become necessary to develop new test procedures and to adapt old ones when new appurtenances come on-line when there are no specific tests related to those devices. This is where we are now in considering appropriate tests for such items as temporary barriers, movable median barriers, and truck- mounted crash cushions. Test criteria must consider new products and be adaptable to as yet unidentified appurtenances.

Another value in uniform test criteria is in the performance certification of new highway safety appurtenances. Performance certification is applicable to all new highway safety systems, whether developed by a public agency or in the private sector. Before a product is exposed to public traffic, it is required to have satisfied the appropriate test performance criteria. The certification process often serves as a screening process. Frequently, Caltrans, like many agencies, is approached by inventors, developers, and salespeople proposing to sell us a better mousetrap. Often, the mousetrap is nothing more than an idea or a few lines on paper. The proposers are informed that we cannot use or even consider their product until it has been shown to safely perform its intended function. NCHRP Report 230 is referred to as the authority for tests to prove the viability of a product. Many of the proposed concepts are abandoned, while others are tested and eventually see use. Many times a product subject to certification testing fails in the minimum matrix. Sometimes the failure is marginal. What is perhaps needed are tolerances for borderline results. Possibly, even a test that barely passes may indicate a need for additional tests. When additional testing is required, what was certification testing frequently becomes research or developmental testing. Many times the added testing results in a greatly improved product.

Considering the foregoing, I believe that the NCHRP Report 230 update should serve as both a foundation for the development of safety appurtenances and as a certification document for the performance of newly developed systems. Research testing should not be downplayed because someone may believe that everything has been invented or improved to its ultimate capability. We know from experience that this is not the case; something new is always coming along. On the other hand, research should not become an endless ritual just because we may learn something. Our primary goal is to be certain that hardware we put out along a road is the safest thing for the intended function.

In-service evaluation is the culmination of the process leading to the adoption of a new safety appurtenance. It also provides the yardstick for evaluating the performance of existing systems. NCHRP Report 230 describes six objectives of in-service evaluation which are still valid. Briefly, they are:

1. Determine whether or not the design goals have been met.

2. Acquire the broadest range of experience and information possible. Tests are usually performed under very narrow idealized conditions. Information on real-world performance is needed.

3. Identify any problems.

4. How has the trial installation fared in the environment?

5. Does the installation interact with or have an effect on adjacent highway operations?

6. Acquire maintenance data relative to costs, manpower, hours, and equipment.

These are basic information items that are needed to decide whether to adopt, reject, or modify the appurtenance being evaluated. Finally, it is necessary to have a uniform format or outline for in-service evaluations. This will assure that the desired information is gathered and that valid comparisons of alternate safety appurtenances can be made.

B. Roadside Features Test Matrices

***By*: James H. Hatton, Jr., Federal Highway Administration**

Full-scale testing of roadside features with highway vehicles, or even with surrogate vehicles (bogies), is expensive. The expense can be viewed from two perspectives. First, we should consider how many times the feature will be replicated in the field. A rather large cash outlay for testing a feature that is to be built many times may in fact not be truly expensive. On the other hand, the same expenditure on testing a one-time-use feature would probably be exorbitant.

The other way to view the cost of full-scale vehicular testing is to ask how much more is likely to be revealed than could confidently be predicted through other, less expensive means. To run a test where the outcome is a near certainty is likely to be wasteful. And, a test to simply determine strength or structural integrity that could just as well be determined through inexpensive analysis or static testing would also be wasteful. Of course, these observations are based on the assumption that there is a rather sizeable body of experience upon which to draw in assessing the risk of missing some flaw in a feature that might only be revealed through full-scale vehicular testing.

Not thoroughly evaluating the test results also has the effect of increasing the cost of full-scale testing because the omission may lead to testing that would not have been needed if a fuller understanding of previous results had been obtained.

In essence, we should be sparing in our demands for full-scale vehicular testing of roadside features, giving consideration to how extensively the results might be applied, what we already know, and what alternative methods are available for evaluating the feature. Additionally, we should learn as much as we can from each test run, with the hope of applying the knowledge gained to other situations.

Ultimately, testing the interaction between vehicles and roadside features should lead to improved roadside safety, and desirably, to more cost effective roadside safety designs. To achieve both of these results, the testing that is undertaken must have relevance to service conditions, and the criteria used to evaluate the test results must take into account both human tolerances to impacts and what is technologically practicable.

In order to be relevant, testing must be conducted with vehicles and with approach speeds and angles that are representative of the upper severity limit of a large portion of accident conditions experienced in the field.

In my view, the current NCHRP Report 230 tests for longitudinal barriers miss the mark a little in this regard. The 4,500-pound automobile, 60-mph, 25-degree test may be a considerably more severe test than automobile traffic is likely to exert on field installations. First of all, that weight automobile is disappearing from our highways. Additionally, the speed-angle combination is unlikely. However, these factors alone do not mean the test is irrelevant. It might be a test that could be used to assess the likely performance of a barrier when struck by heavier vehicles, say pickups and vans, or even larger trucks or buses under less severe impact conditions. The problem here is that these other vehicles have larger front wheels, different and higher bumpers, and higher centers of gravity. Thus, the 4,500-pound automobile test is not likely to be a good predictor of a barrier's performance with these other vehicles.

I would also point out that the bus tests that are in NCHRP Report 230 are not representative of vehicles that account for a significant portion of the heavy vehicle barrier accidents, namely, truck semi-trailers. Nor are the intercity bus tests likely to give much insight on how a barrier and semi-trailers will interact. So, if your goal is to discover how likely a barrier is to contain semi-trailers, you probably need other tests.

In the designing of the test matrix (Figure 2) which is from the proposed AASHTO Guide Specifications for Bridge Railings, there was a very deliberate effort to match the tests to what were perceived as the barrier performance requirements for various highway conditions. Admittedly, there was some compromise and rationalization to avoid too radical a departure from past practices. Nevertheless, I believe it is a good fit with reality. The one place where the relevance of the matrix might be challenged is the 18,000-pound truck test. That truck does not represent a significant problem on our highways. It was selected for its front-end similarity to semi-trailers, its availability, its relatively low cost, and its relative ease of handling in crash tests. It is believed to be a stand-in for an empty semi-trailer.

In order to accurately compare the results between tests, we need tighter controls on how tests are run. Note that the guide specifications test matrix goes a little way in that direction. However, for feature acceptance testing we need much more detailed descriptions of the vehicles to be used for testing. Tire sizes, wheel designs, suspension systems, wheel set backs, wheel bases, and bumpers (in short, the basic geometry, weight and structure of the test vehicles) need to be rather tightly specified if we are to accurately determine the performance differences between various feature designs.

For example, in a recent series of tests, three nearly identical tests were run on one barrier with similar, satisfactory results in each instance. A fourth test against a slightly different barrier gave significantly less desirable

PERFORMANCE LEVELS		TEST SPEEDS -- mph [1,2] — TEST VEHICLE DESCRIPTIONS AND IMPACT ANGLES			
		Small Automobile W = 1.8 Kips A = 5.4' ±0.1' B = 5.5' H_{cg} = 20" ±1" θ = 20 deg.	Pickup Truck W = 5.4 Kips A = 8.5' ±0.1' B = 6.5' H_{cg} = 27" ±1" θ = 20 deg.	Medium Single-Unit Truck W = 18.0 Kips A = 12.8' ±0.2' B = 7.5' H_{cg} = 49" ±1" θ = 15 deg.	Van-Type Tractor-Trailer [4] W = 50.0 Kips A = 12.5' ±0.5' B = 8.0' H_{cg} = See Note 4 R = 0.61 ±0.01 θ = 15 deg.
PL-1		50	45		
PL-2		60	60	50	
PL-3		60	60		50
CRASH TEST EVALUATION CRITERIA [3]	Required	a,b,c,d,g	a,b,c,d	a,b,c	a,b,c
	Desirable [5]	e,f,h	e,f,g,h	d,e,f,h	d,e,f,h

Notes:

1. Except as noted, all full-scale tests shall be conducted and reported in accordance with the requirements in NCHRP Report No. 230. In addition, the maximum loads that can be transmitted from the bridge railing to the bridge deck are to be determined from static force measurements or ultimate strength analysis and reported.

2. Permissible tolerances on the test speeds and angles are as follows:

   Speed -1.0 mph +2.5 mph
   Angle -1.0 deg. +2.5 deg.

   Tests that indicate acceptable railing performance but that exceed the allowable upper tolerances will be accepted.

3. Criteria for evaluating bridge railing crash test results are as follows:

   a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.

   b. 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.

   c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.

   d. The vehicle shall remain upright during and after collision.

Table G2.7.1.3A Bridge Railing Performance Levels and Crash Test Criteria

Figure 2

Notes (cont.):

e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle or, in the case of a combination vehicle, the rear of the tractor or trailer does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.

f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ:

μ	Assessment
0 - 0.25	Good
0.26 - 0.35	Fair
> 0.35	Marginal

where $\mu = (\cos\theta - V_p / V) / \sin\theta$

g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0-ft. longitudinal and 1.0-ft. lateral displacements, shall be less than:

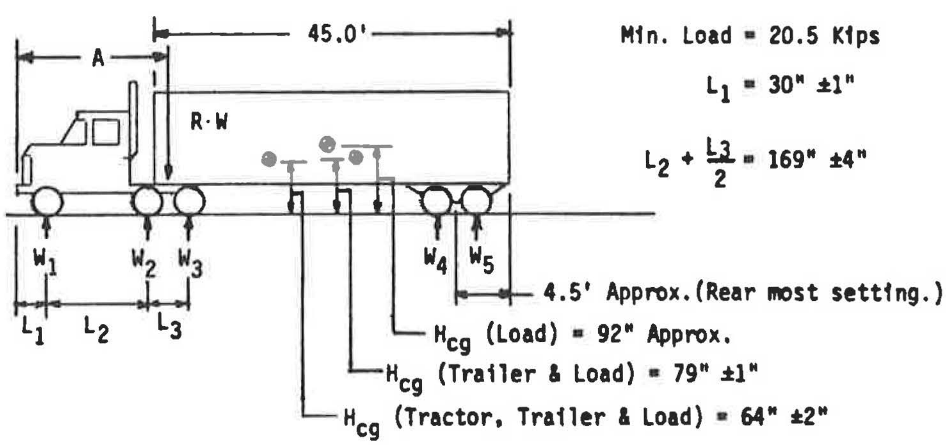
Occupant Impact Velocity - fps	
Longitudinal	Lateral
30	25

and the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than:

Occupant Ridedown Accelerations - g's	
Longitudinal	Lateral
15	15

h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20-ft. from the line of the traffic face of the railing. The brakes shall not be applied until the vehicle has traveled at least 100-ft. plus the length of the test vehicle from the point of initial impact.

4. Values A and R are estimated values describing the test vehicle and its loading. Values of A and R are described in the figure below and calculated as follows:



Min. Load = 20.5 Kips

$L_1 = 30" \pm 1"$

$L_2 + \frac{L_3}{2} = 169" \pm 4"$

$$A = L_1 + \frac{W_2 L_2 + W_3 (L_2 + L_3)}{W_1 + W_2 + W_3}$$

$$R = \frac{W_1 + W_2 + W_3}{W}$$

$W = W_1 + W_2 + W_3 + W_4 + W_5$
= total vehicle weight.

5. Test articles that do not meet the desirable evaluation criteria shall have their performance evaluated by a designated authority that will decide whether the test article is likely to meet its intended use requirements.

Table G2.7.1.3A (cont.) Bridge Railing Performance Levels and Crash Test Criteria

Figure 2 (continued)

results. But the truck used in the fourth test was not the same make as those used in the first three tests. Thus, we are left with the question of whether the change in test vehicle or the change in the barrier caused the change in results.

In regard to occupant risk, a free falling object, starting from rest, will reach a speed of 40 fps after falling 24.9 feet. NCHRP Report 230 describes a 40-fps occupant impact as not life threatening. I do not believe this. The maximum design delta V of 30 fps recommended in NCHRP 230 correlates to a fall of 15 feet--probably survivable. One would undoubtedly voluntarily accept such a fall if the alternative were death, but there is no guarantee that the fall would not result in serious injury, or even death.

The purpose of NCHRP Report 230 was not to serve as guidance for the acceptance of roadside features. However, it has become the basic document on the subject. In the next writing of NCHRP Report 230 we had better recognize this fact and give much more thought to the recommended design (acceptance) delta V's and do more to explain what they mean. Many people do not seem to recognize that relatively low speed impacts have the potential of being injury producing and have said, "If we can design crash cushions for 30 fps, why not sign and luminaire supports?" The answer is that there are vast technological and cost differences in achieving higher levels of performance from the differing types of features.

As a final thought on NCHRP Report 230, I would like to say that I believe it was an excellent work when it was produced. However, I have come to view it as a backward looking document. I would hope the next version of NCHRP Report 230 would look to the future, provide more guidance for designing test procedures for features or conditions we have not yet encountered. There should be a built-in test design philosophy. And I will reject that philosophy, out of hand, if it contains the word linkage. Linkage is a term sometimes used in arguing to maintain a given test over a superior alternative test. The advocates of linkage believe that the link with historic testing justifies its use.

C. Crash Test Instrumentation and Evaluation

By: **Dean Sicking, Texas Transportation Institute**

This presentation examines current crash test instrumentation and evaluation standards described in NCHRP Report 230. In the interest of brevity, I will concentrate only on those areas where modification of the current standards should be considered. As a result, this presentation may sound very negative toward current standards and imply that NCHRP Report 230 was in some way deficient. Nothing is further from the truth. NCHRP Report 230 represented a major improvement in crash test evaluation criteria at the time it was published and has served the safety community well for the last seven years.

Occupant Kinematics

NCHRP Report 230 evaluates the potential for injury during a crash test in terms of the velocity at which an unbelted occupant impacts the interior of the vehicle. The unbelted occupant is modeled as a free missile in the vehicle. Impact with the car's interior is assumed to occur after the free missile travels 2 ft. forward and 1 ft. laterally relative to the vehicle. Longitudinal and lateral impact velocities are estimated by independently integrating longitudinal and lateral accelerometer readings.

This greatly simplified approach can lead to a significant underestimation of actual occupant impact velocities. The biggest source of potential error in occupant impact velocity estimates is associated with the assumption that an occupant impacts the vehicle interior after traveling only 1 ft. laterally. Crash tests of roadside barriers indicate that drivers often are projected across the vehicle and first impact the vehicle's interior at the A pillar on the passenger side of the vehicle. Since, for these cases the occupant travels more than 3 ft. before impacting the vehicle, actual impact velocities are much more than predicted by the NCHRP Report 230 evaluation criteria.

Another potential source of error in occupant impact velocities is related to differences between the vehicle's velocities at the center of gravity and at the point of occupant impact. High speed rotations during an impact give each point in the interior of the vehicle a different velocity relative to the occupant. Analysis of crash test results indicate that the vehicle velocities at the edge of the interior are commonly as much as 4 ft./sec. different in the longitudinal direction and 2 ft./sec. different in the lateral direction. These differences alone represent more than ten percent of the recommended occupant impact velocities.

Occupant ridedown acceleration after impact with the vehicle interior is another primary measure of occupant risk used in NCHRP Report 230. Although accelerometers are placed as near the center of gravity of the vehicle as possible, no effort is made to record the exact location of accelerometer mounts. Crash test and simulation results have shown that accelerations at various points in the interior of the vehicle can vary significantly. Thus, crash test results not only do not give actual vehicle accelerations at the point where an occupant would be pressed against the vehicle interior, the data do not indicate the actual accelerations at the center of gravity of the vehicle.

Elimination of all of these inaccuracies in the estimate of actual occupant impact velocities requires a complete knowledge of the full 3-D motion of the vehicle. Although NCHRP Report 230 recommends vehicles be instrumented with triaxial accelerometers and rate gyros to measure vehicle accelerations and rotation rates in each direction, problems with the differentiation of rate gyro data prevent the accurate determination of vehicle motions from existing crash test data. This problem could be overcome by placing rate gyros with two additional triaxial accelerometers mounted at different points within the vehicle. If the additional cost of the triaxial accelerometers is determined to be excessive, approximate methods for estimating occupant impact velocities could be developed that would account for some of the inaccuracies described above with little or no increase in the cost of accident data collection and analysis.

Wheel Snag

Wheel snagging on roadside barrier elements is generally described by NCHRP Report 230 as unacceptable. This philosophy is based on the premise that wheel snagging generates high deceleration forces and/or post-impact spinout or possible overturn and can thereby increase the probability of occupant injury. However, numerous crash tests have indicated that vehicle accelerations can remain within acceptable limits, even during relatively severe wheel snag events. Further, these tests have shown that wheel snag usually prevents impacting vehicles from exiting the barrier at a high angle and reentering the traffic stream. A new standard for evaluating the severity of wheel snagging during barrier impacts should be developed to properly consider the occupant risk associated with this behavior.

Vehicle Velocity Change

NCHRP Report 230 recommends that the post-impact trajectory of test vehicles be evaluated to determine the risk associated with a disabled vehicle reentering the traffic stream. This criterion requires that impacting vehicles exit a barrier at an angle no more than 40% of the impact angle and that, if the vehicle trajectory would cause the vehicle to penetrate into adjacent traffic lanes, the total velocity change during impact should be less than 25% of the impact speed. Exit angle is used as a measure of the propensity for the vehicle to penetrate into opposing traffic lanes and is measured when the vehicle first loses contact with the barrier. The vehicle's angle relative to the barrier often continues to increase long after loss of contact with the barrier; and although a test vehicle's exit angle may be less than the required limit, the vehicle can still penetrate adjacent traffic lanes at angles much above this value. Further, determination of when a vehicle would penetrate into adjacent traffic lanes is very subjective, and additional clarification is definitely necessary.

The limit on total velocity change of 25% of impact velocity has been found to be more restrictive than any other criterion for 25 degree impacts. The concept behind this limitation is that, if a vehicle reenters the traffic stream at a low speed, there is a high potential for other traffic impacting it in the rear. There is little or no evidence that rear end collisions after barrier impacts represent a significant fraction of injury producing barrier accidents. Further, very few of the barriers in wide use today can meet this strict velocity change requirement. As shown in Table 1, most standard guardrail designs and a vertical concrete wall would fail the velocity change requirements. A careful review of post impact trajectory requirements should be undertaken to determine if rear end impacts are a potential source of injury accidents and if exit angle limitations are the best method for evaluating the potential for vehicles crossing into opposing traffic lanes.

Occupant Compartment Intrusion

NCHRP Report 230 generally describes penetration or intrusion into the occupant compartment as an unacceptable behavior. Although occupant compartment penetration can lead to catastrophic accidents under some circumstances, there are many situations where minor penetration or intrusion poses little or no threat to vehicle occupants. For example, many small highway signs are designed to break away during impacts. Under low speed impact conditions, the remaining post stub can scrape along the bottom of the vehicle and actually cut small holes in the floor pan. Although these test results are often interpreted as failing NCHRP Report 230 safety standards due to this minor occupant compartment penetration, the incidence of occupant injury arising from such impacts is extraordinarily low. The update of NCHRP Report 230 should incorporate a more discerning measure of occupant compartment intrusion in recognition of the potential for inconsequential vehicle intrusion or penetration.

TABLE 1 Velocity Changes During Longitudinal Barrier Impacts

Vehicle Weight (lbs)	Impact Velocity (mph)	Impact Angle (deg)	Service	Velocity Change (mph)
4450	61.8	25.3	G4 (1S) on Box Culvert	24.6
4500	58.2	25	G4 (1S) at Turned Down End	29.4
4490	58.7	25	TSDHPT Guard Fence at Turned Down End	22.6
4490	58.5	23	TSDHPT Guard Fence at Turned Down End	19.2
4740	59.9	24	Rigid Vertical Wall	17.5
4490	61.8	25.6	Rigid Vertical Wall	15.9

Flail Space Model

The flail space model for occupant risk evaluation contained in NCHRP Report 230 may be the best available procedure for estimating the probability of injury during an accident. However, if the flail space model is to be used to compare the performance of various roadside appurtenances, it is important to accurately determine occupant impact velocities and ridedown accelerations. Current data acquisition and reduction procedures are inadequate for this task. If the cost associated with additional vehicle instrumentation proves to be excessive, improved data reduction procedures must be developed for gleaning as much information as possible from available crash test data.

Summary

Although current crash test evaluation criteria contained in NCHRP Report 230 have generally improved the overall level of safety along the nation's roadways, current applications of the document are far beyond the purposes originally intended by the authors. The document was intended as a general guide for research agencies to follow in the evaluation of new safety hardware. NCHRP Report 230 has become a certification standard against which all safety hardware must be compared. Any update of this report will likely be used in a similar fashion. As a result, evaluation criteria must be as objective as possible with a minimum of the subjective language now found in the report.

D. Review of Biomechanical Impact Response and Injury in the Automotive Environment

By: **John W. Melvin, General Motors Research Laboratories**

Mr. Melvin submitted as a summary of the material presented in his talk the executive summary of Task B of Phase 1 of a DOT contract titled Advanced Anthropometric Test Device Development Program. His summary is titled, "Review of Biomechanical Impact Response and Injury in the Automotive Environment" and was co-authored by Kathleen Weber.

"This review includes literature through 1984 and is divided into chapters covering the following body regions: head, spine, thorax, abdomen, pelvis, and lower extremities. Each chapter includes information on anatomy; clinical injury experience; biomechanical response to impact; and injury mechanisms, tolerance, and criteria from laboratory studies. Each chapter also contains its own reference list and thus can stand alone as a review of the literature on that region of the body. Summaries of each chapter follow.

Head

The head is considered the most critical part of the body to protect from injury because of the irreversible nature of injury to the brain. In the Injury Priority Analysis, head injury constitutes nearly 45% of the total Injury Priority Rating (IPR, this percentage indicates the relative contribution of injuries in each body region to the total societal cost of all automotive injuries). Facial injury, however, accounts for an additional 10.5%. The costly facial injuries are primarily lacerations to younger occupants. While these injuries are not likely to be life threatening, the impairment to the individual from facial nerve damage and/or facial disfigurement as well as the need for reconstructive surgery make such injuries relatively costly to society.

A variety of mechanisms have been postulated for mechanical damage to the brain from impacts to the head. They include: (1) direct brain contusion from skull deformation at the point of contact; (2) indirect brain contusion produced by negative pressure on the side opposite the impact; (3) brain contusion from movements of the brain against rough and irregular interior skull surfaces; (4) brain and spinal cord deformation in response to pressure gradients and motions relative to the skull, resulting in stress in the tissues; and (5) subdural hematoma from movement of the brain relative to its dural envelope, resulting in tears of connecting blood vessels. The latter three mechanisms have also been postulated for mechanical damage resulting from head motions due to indirect impact.

The data presently available for defining the response of the head to impact are limited to rigid impacts and are predominantly based on embalmed cadaver tests. The data are adequate to define general response specifications for rigid impacts to the front and side of the head, in terms of peak contact force over a range of impact velocities from 1 to 8 m/s. The corresponding acceleration response data are limited to an impact velocity range of 1 to 5 m/s.

There is a need for additional studies to define the impact response of the human head using unembalmed cadavers with rigid impact surfaces and current acceleration measurement techniques. A repeatable and reproducible method for producing padded impacts also needs to be developed to allow cadaver studies to be conducted for padded head impact response definition.

The parameters of head motion that have been associated with the production of brain injury are translational acceleration, rotational acceleration, and rotational velocity. Of these, most attention has been given to translational acceleration in terms of developing head injury criteria. For direct impacts to the head, the Wayne State Tolerance Curve and the Japan Head Tolerance Curve, both based on head translational acceleration, are in close agreement. Injury criteria that have evolved from the tolerance curve approach would be expected to provide accurate assessment of injury potential during direct head impacts.

The Head Injury Criterion (HIC), based on the resultant translational acceleration of the center of gravity of the head, is the most commonly used method of evaluating head impact data. Statistical analysis of direct head impact cadaver test data has been used to define the relationship between HIC values and the probability of sustaining a particular level of injury, thus providing a continuous ability to interpret HIC values. A HIC level of 1000 was found to produce an expected 16 percent incidence of life-threatening brain injury to the adult population.

The validity of the HIC for long duration and non-contact head accelerations remains in question. Injury criteria based on head angular acceleration and angular velocity have been proposed for such situations, but they lack the extensive evaluation and review that has been given the HIC for short duration (less than 15 ms) head impacts. Mathematical models of the head hold promise for evolving into injury predictive models given proper development and evaluation. Simple models, such as the mean Strain Criterion (MSC), which are based on translational acceleration, have the potential for describing the dependence of the injury response on impact waveform and direction of impact. The application of the MSC to dummy head accelerations, however, remains to be developed. More sophisticated finite element models of the brain and skull have been developed, but their complexities and lack of validation have hampered their development into injury predictive models.

The response of facial structures to impact loads has been studied to a limited extent. The fracture and collapse of the facial bones during distributed loading significantly reduces the peak forces and resulting head accelerations in comparison to those produced by similar impact tests to the skull.

The tolerance of the facial bones to direct impact loading has been studied by a number of researchers, and fracture loads for individual bones and the whole face have been determined. The failure characteristics of facial soft tissues due to laceration from sharp edges have been studied, and rating systems for the assessment of the severity of the lacerations have been developed. There is a need, however, to study the mechanisms of lacerations to facial tissue due to blunt impact.

Spine

The vertebral column is the principal load-bearing structure of the head and torso and provides a flexible protective pathway for the spinal cord. Injuries that affect the function of the spinal cord can result in death, quadriplegia, or paraplegia. Despite these potentially serious consequences, the actual incidence of such injuries is relatively low, and thus they contribute probably less than 6% to the total IPR. (This figure is uncertain because NASS does not code the spine directly but rather incorporates it into the neck and back regions.)

The static and dynamic response of the head/neck system to indirect inertial loading at low crash severities has been studied extensively in volunteers and, to a lesser extent, in cadavers. These studies have included frontal, lateral, and oblique impacts. Specifications for suitable neck linkage systems, ranges of motion, and joint resistance characteristics are available from the published literature. Direct crown loading experiments have also produced data on the superior-inferior compliance of the cervical spine in cadavers.

The static midsagittal bending response of the thoraco-lumbar spine has been studied in volunteers for flexion and extension. Specifications in terms of overall rotation ranges and bending resistance characteristics of the rotation of the thorax relative to the pelvis have been produced. The equivalent dynamic data are quite limited but do indicate the presence of upper thoracic spine mobility with values similar to those for lower spine mobility.

The status of knowledge on the tolerance of the neck to loading is limited. Of necessity, all volunteer data are below the injury threshold. Additionally, injury mechanisms can be quite different than those mechanisms controlling response. Most injury threshold data are either based on cadaver tests or on reconstructions of accidents with instrumented dummies. As such, the threshold values are subject to the limitations associated with the surrogate used to obtain the data. These data sources have been used to develop limiting tolerance values for neck bending moments in midsagittal flexion and extension, axial compressive and tensile neck forces, and neck shear forces. No efforts have been made at this time to develop limit values associated with combinations of the various forces and moments. Corresponding studies of the tolerance of the thoracolumbar spine are not available. The only tolerance studies done on the thoracolumbar spine are those related to vertical accelerations.

Thorax

The thorax houses most of the body's vital organs and is thus the next most critical region, after the head, to protect from injury. Injuries to the chest constitute nearly 19% of the cost to society of injuries sustained by automobile occupants, as calculated using the Injury Priority Analysis. The nature of thoracic injury, however, is such that there are few long-term disabilities. In general, the victim either dies soon after impact or recovers completely.

The most critical injuries are those to the internal organs. In most experimental studies using cadavers, however, injury rating has been based on skeletal damage. As thoracic skeletal deflection increases under dynamic loading, the force resisting the motion remains somewhat constant. Further deflection begins to produce rib fractures, which can be followed by the sudden appearance of internal soft tissue injuries as the skeletal structure collapses. It is necessary, therefore, to be conservative in defining thoracic injury criteria in terms of deflection levels related only to rib fracture because of the instability of the thoracic structure under such conditions. Applied load by itself is also inadequate as an injury criterion, because of its insensitivity to increasing deflection in the force-plateau region characteristic of dynamic thoracic response.

Another factor that must be considered in defining thoracic injury criteria is the fact that thoracic response to impact loading is highly rate-sensitive. Viscous and inertial forces dominate the initial response, and elastic forces become significant only as large deflections of the system occur. Some forms of pulmonary and cardiac injuries have been found to occur only in conditions of high impact velocities with very little chest deflection. The rate of thoracic deflection as well as the degree of deflection can both be important parameters in describing the injurious effects of an impact to the chest, and they should both be considered in the development of general thoracic injury criteria.

In terms of response, the sensitivity of the thoracic structure to the rate of loading makes it difficult to interpret the findings from different types of experiments without accounting for this variable. For instance, the strip loading produced by the shoulder belt may produce an apparent stiffness that is lower than that produced by a flat circular impactor, due to differences in shape and area of loading. The rate of loading in shoulder belt tests, however, is usually much lower than that of the typical impactor test, thereby confounding the interpretation of shoulder belt interactions with the thorax. Impactor mass is a variable that can also strongly affect the apparent response of the thorax and must be accounted for when comparing experimental results.

Flat circular impactor tests tend to produce a characteristic thoracic force-deflection response that consists of an initial linear region, followed by a plateau region of almost constant force, and finally, if the impact has sufficient severity, a third region of increasing stiffness. This general form of response has been shown to be true for both frontal and side impact and with volunteers as well as cadavers. Thoracic structural rate sensitivity appears to be responsible for much of the initial stiffness and for the subsequent plateau in force as the rate of loading decreases during the impact. However, the distribution of load by the flat impactor surface must play some role in determining the response, since shoulder belt loading does not appear to produce the plateau region, even when loading rates are taken into account. Such local loading effects are not, however, well documented.

Because of the complexities of thoracic response, simple elastic structural representations are inadequate to guide the designer of mechanical analogues of the thorax. Instead, representation by means of spring-mass-damper models and/or transfer function approaches are necessary to provide the designer with the proper insight into the relative contributions of elastic, viscous, and inertial forces to the overall system response.

The three-dimensional structure of the thoracic skeleton and its contents requires deformation descriptors that are global in nature to provide an omnidirectional description of response. In the cadaver, this has been accomplished to some degree by the use of arrays of accelerometers on the periphery of the thorax. Similar or alternative methods of global response measurement will be necessary in the AATD to ensure adequate capability to assess injury potential in different directions and under different types of loads and loading rates.

Abdomen

The abdomen includes the organs and viscera below the diaphragm and above the pelvic girdle. Although there is little bony structure to protect these organs from blunt impact, injuries to this region contribute only 7.5% to the total IPR. Like the thorax, the abdomen can be the site of injuries induced by restraint systems themselves, including belts and steering systems. As far as the crucial organs are concerned, the liver, spleen, and kidneys are most frequently injured, and these injuries tend to be the most serious and life- threatening.

Injury mechanisms in the abdomen are thought to be primarily the result of deformation or penetration of the abdominal contents along with significant force or pressure generation in the deformed organs. In addition, solid organs, such as the liver, may undergo severe damage due to pressure generation alone at high impact velocities. There is evidence to show that these organs are viscoelastic, that the rate of loading is a crucial factor in injury causation, and that a compressive stress of 300 kPa (43 psi) will cause a superficial liver injury. Regarding dynamic response of the abdomen, the problem is complicated by the fact that there is a variety of surface geometries and component materials that can impact the upper abdominal area in a vehicle crash environment. In side impacts, however, the surfaces such as doors and armrests are somewhat well-defined, and dynamic load-deflection response curves do exist to a limited extent for lateral impact. Much more research data are needed, however, before abdominal response to impact can be fully quantified.

Pelvis and Lower Extremities

The pelvis is a bony structure that transmits the weight of the torso to the lower extremities during normal locomotion and supports the torso in the seated position. In an automotive impact environment, it can sustain injury from both frontal and side impact, and, during aircraft ejection or vertical falls, it is called upon to take the entire inertial load from seat-to-head acceleration. Injuries to the pelvis, however, contribute only about 1% to the total IPR. This structure is important, therefore, primarily for its response during load transmission.

The lower extremities constitute approximately one-third of the body weight, and, during normal locomotion, are required to withstand large dynamic loads. Injuries to the lower extremities of automobile occupants are rarely fatal but require significantly longer periods of hospitalization and lost working days than injuries to other body regions at the same AIS level. Even so, injuries to this region constitute only a little more than 5% of the total IPR.

The frontal impact response of the knee/femur/pelvis complex during seated knee impacts has been studied extensively. This research includes information on the acceleration-time histories, impedance, and effective mass. Other studies have defined the geometry of engagement of the knee into crushable padding. Load-deflection data are also available for subluxation of the tibia with respect to the knee joint. Lateral response of the pelvis has been studied for both impactor and flat-wall impacts and has been described in terms of force-time histories and pelvic acceleration-time histories.

Injury tolerance data for the knee/femur/pelvis complex consists primarily of axial loads in the femur.

Lateral loading tolerances for the pelvis are available in terms of forces and peak accelerations. For the femur, tolerance to lateral impact can be defined in terms of maximum bending moment as can the loading tolerance of the tibia in the transverse direction. There is also information on the strengths of the knee-joint ligamentous structures."

E. Crash Test Conditions and Tolerances

By: **King Mak, Texas Transportation Institute**

This presentation examines and takes issue with some of the specified crash test conditions and tolerances as outlined in NCHRP Report 230 and the new guide specifications for crash testing of bridge railings. It is not possible to cover many items within this short period of time, so I will just highlight a few items to stimulate more thought and discussion on this topic during this meeting.

Impact Speed and Angle

NCHRP Report 230 specifies tolerance on the impact condition using the composite term of impact severity, IS, which is defined as:

$IS = 1/2m(v \sin \Theta)^2$ where:

m = vehicle test inertial mass in slugs,
v = impact speed in feet per second, and
Θ = impact angle in degrees.

The tolerances are even tighter on the new bridge rail guide specifications with -1.0 and +2.5 mph on the impact speed.

For a reverse tow and cable guidance system used for passenger cars and light trucks, the impact angle can be well controlled and meeting the specified angle is generally not a problem. Impact speed is somewhat harder to control, depending entirely on the skill of the driver in the towing vehicle. Thinking of our everyday driving, it is not easy to maintain a constant speed even with cruise control.

Now for the driver of the towing vehicle, he has to be concerned first with getting the test vehicle up to speed. Any surface discontinuity, such as a slick spot or an uneven pavement joint, could cause the towing vehicle to temporarily lose traction and speed. He also has to be concerned with exceeding the desired speed since slowing down of the towing vehicle could introduce slack into the tow cable and temporary loss of control on the vehicle being towed.

The problem is much worse for tractor-trailers and other heavy vehicles tested under their own power, using a radio remote control system. Here a push truck is first used to accelerate the test vehicle up to 35-40 mph. The clutch and throttle of the test truck are then engaged and the vehicle continues accelerating to the desired speed. A governor is usually used to control the top speed of the test vehicle. The test truck is steered using radio remote control by an operator in a chase car.

It is not difficult to see that a lot can go wrong with this system that could result in the impact speed or angle not meeting the specifications. I will just mention a few that we have unfortunately experienced: loss of contact between the push and test vehicles due to yawing of test vehicle as the clutch and accelerator were engaged, sudden unexplained loss of engine power in the test vehicle, interference in the radio frequency, and failure of an electronic component in the remote control unit. The change from a tail wind to a head wind situation could significantly affect the acceleration ability of the test vehicle and result in the difference of 3 to 4 mph in the impact speed. Everything has to work properly in order to meet the specified tolerances.

Point of Impact

Control for point of impact is no problem with a reverse tow and cable guidance system, but an area of concern for the remote control system. At an impact angle of 15 degrees, one foot variation in the path of the vehicle means four feet difference in the point of impact. This could be important for a post-and-beam type of barrier. Another situation in which a slight error in the point of impact could have significant effect is with testing of multi-leg sign supports. Because of the requirement that all legs of the sign support must be impacted simultaneously, along with the narrow track width of an 1,800-pound car, a slight offset in the impact point could result in a large difference in forces acting on each of the sign supports, rotation in the vehicle, or even damage to tires from the stubs in the ground.

Another issue is on what is the appropriate point of impact for various appurtenances. For beam-and-post longitudinal barriers, one of the concerns is for snagging and/or pocketing. The critical impact location in this case would be the point at which the potential for snagging is maximized. Impacting too close to the snag point would allow a vehicle to clear the snag point before guardrail deflections and vehicle penetration become large enough to allow snagging and/or pocketing. On the other hand, impacting too far upstream from a snag point may allow sufficient vehicle redirection before the snag point is reached. It should also be noted that the critical impact point changes with the stiffness of the barrier.

For example, the specified point of impact for a transition is 15 feet upstream from the more rigid system. Computer simulation and prior crash test results indicate that the critical location for a W-beam guardrail system is at a distance of 7 to 8 feet upstream from the more rigid system. Another example is on a concrete beam and post bridge rail system. When impacted near a post, the vehicle was smoothly redirected and the bridge rail successfully passed the NCHRP Report 230 evaluation criteria. However, when a very similar system was impacted further upstream from a post to maximize the potential for snagging, severe wheel and hood snagging were observed.

Soil Condition

The soil type and embedment practice have major effects on the performance of "breakaway" sign supports and, to a lesser extent, on longitudinal barrier systems. The use of the strong soil (S-1) is probably reasonable for many safety appurtenances. Even so, the depth, surface radius of embedment material, and soil moisture content are some topics that need to be further evaluated.

The weak soil (S-2) is much more of a problem. For example, NCHRP Report 230 specifies 2 to 10 percent of fines passing the No. 100 sieve for the weak soil with no mention of cohesiveness. We have been using river bottom sand with a fines content of 4 percent for our weak soil pit and the soil has little cohesion and very low resistance. By increasing the fines content to 10 percent with clayey material (still within the limits of the specification), the soil will have very high cohesion and resistance. The soil moisture content can drastically affect the soil strength since the clayey material has virtually no strength when saturated, but very high strength when dry.

Test Vehicle Properties

In NCHRP Report 230, the properties of test vehicles are specified in terms of mass, mass moments of inertia, and certain basic dimensions. Even with the guidelines, tests of two "identical" cars on the same appurtenance may have significantly different results due to variations in such vehicle factors as chassis alignment, suspension system, shock absorbers, tires, etc. Thus, to reduce variability introduced by the test vehicles, one may want to tighten the specifications on the test vehicle, perhaps even to the point of specifying vehicle years, makes and models.

The new bridge railing crash test matrix is much more specific in terms of the test vehicle properties, which is understandable in efforts to improve the repeatability of crash tests. However, it is also important to make sure that the specifications are such that the test vehicle represents a common class of vehicles on the highway and can thus be purchased readily and economically. In my opinion, the new bridge rail specifications failed to meet this requirement. We have great trouble in locating vehicles that fit the specifications and, on several occasions, had to physically alter some vehicle properties in order to meet the specifications. For example, we had to move the axle locations on several trucks to meet the wheelbase requirements.

Needless to say, this greatly increases the cost for acquiring the test vehicles which is a major cost factor in crash testing. A balance has to be attained between specificity and repeatability and costs involved in meeting the specifications.

Instrumentation

Instrumentation is another area that needs to be considered. For instance, 50-g accelerometers are used due to the high-g environment of the crash testing conditions. A one-percent accuracy, which is good accuracy, means the difference of 0.5 g which is fairly insignificant by itself. However, for a sign test, 0.5 g over duration of the impact, e.g., 150 milliseconds, could mean a velocity change of 2.4 feet per second, which is 16 percent of the acceptance threshold of 15 feet per second.

Another example is the number and placement of accelerometers and possibly rate gyros. Currently, one set of accelerometers is typically placed near the vehicle c.g. to measure longitudinal, lateral and vertical components of accelerations. Data from these measurements are then used to compute changes in vehicle velocity and occupant impact velocities from the flail-space model. For impacts with longitudinal barriers or other features that cause the vehicle to undergo rapid changes in angular position, major errors can occur in the computation of vehicular velocity change and occupant impact values. The errors increase as the distance from the accelerometer position to the c.g. increases. It should be pointed out that it is often difficult to place the accelerometer at the vehicle c.g. due to seat locations and/or the structural aspects of the test vehicle.

Discussions

Finally, there are three specific points that I would like to bring up regarding future consideration and determination of the crash test conditions and tolerances.

First, the crash test conditions and tolerances should be determined on the basis of cost-effectiveness considerations. On the one hand, we would like to minimize any vagueness or ambiguity in the specifications to assure uniformity and consistency among all testing agencies so that the test results are more precise and repeatable. On the other hand, it is important to bear in mind the economics of tightening the specifications and the economic burden placed on the highway agencies designing and developing new or improved roadside safety appurtenances. The state-of-the-possible may not necessarily be economically feasible. A balance has to be struck between these two conflicting goals to come up with a balanced set of specifications.

Secondly, despite the considerable amount of crash testing done in the past twenty-five or so years, there is still a lack of information on the effects of the various test conditions on the results of the crash tests. For example, how important is the difference of three miles per hour from the target impact speed of 50 miles per hour? We had the misfortune of finding that out. A test was repeated three times because the impact speed was three miles per hour lower than the target speed in the first two tests. From the standpoint of the vehicle dynamics, there was hardly any difference between the three tests. From the standpoint of force or loading on the barrier, the higher speed impact did have higher force or loading as expected, but the difference was roughly proportional to that between the squares of the impact speeds. Could the results from the lower speed impact be extrapolated to the target speed and avoid the expense of rerunning the test? I think that these are some of the questions that we need to address in establishing the tolerances for the various test conditions.

The third and perhaps the most important point concerns the purpose of crash testing. I think there is one underlying philosophical issue that must be addressed first. If the purpose of crash testing is to conduct research and development, we can probably afford greater variance in the test conditions and tolerances and to test for the worst case scenario. If the test purpose is to demonstrate the prototype device at the "certification" level, we may want to tighten the specifications since it would not be to the advantage of the agency to test at the worst possible condition. Unfortunately, these two purposes are oftentimes at odds with each other.

Take testing of a transition design as an example. The specified point of impact is 15 feet upstream from the more rigid system, but the most critical point of impact may be 8 feet upstream from the more rigid system. If the test purpose is strictly research and development, the point of impact should be the most critical location, or 8 feet upstream. However, if the purpose is also "compliance," then it would be to the benefit of the agency to use the specified point of impact, or 15 feet upstream. Testing at the more critical point could result in unacceptable performance and hence rejection of the appurtenance.

In summary, I have outlined a few areas under the general topic of "Crash Test Conditions and Tolerances" that I believe need further consideration as the NCHRP Report 230 requirements are being updated. These are by no means inclusive and they are intended to stimulate more thoughts and discussion on this topic during this workshop. I am sure that many more topics and issues will be raised during the course of this workshop that would benefit the update of the NCHRP Report 230 requirements.

F. Using Surrogate Test Vehicles

***By*: Martin W. Hargrave, Federal Highway Administration**

The Federal Outdoor Impact Laboratory (FOIL) at the Turner-Fairbanks Research Center of FHWA at McLean, Virginia uses a test bogie in place of a real car for crash tests of breakaway sign and luminaire supports. The test bogie is made up of a steel framework on car wheels with a crushable front end. The crushable front end was designed to simulate the crash of a real car when impacting a breakaway roadside device. During a crash test, the crushable front end is collapsed but the rest of the bogie is generally undamaged. The aluminum honeycomb blocks used in the crushable front end are relatively inexpensive and easily replaced. Thus, crash tests with a bogie can replace real car tests that are much more expensive and time consuming to perform.

Searching back in the ancestry of the bogie used at FOIL, we find there were several generations of surrogate test devices. These were:

- Rigid Nose Pendulum (Prototype Only)
- Crushable Nose Pendulum (Prototype without Slider)
- Crushable Nose Pendulum (with Neoprene Faced Slider)
- Crushable Nose Pendulum (with Aluminum Honeycomb Faced Slider)
- Low Speed Bogie (2250 lbs/20 mph)
- "Breakaway" Bogie (1850 lbs/up to 60 mph)

The "breakaway" bogie currently used at the FOIL has been validated for the testing of breakaway supports. Recently a major test program was completed using the bogie to crash test 44 luminaire supports. Several types of breakaway bases were tested including slip bases, transformer bases, couplings, anchor bases and progressive shear bases.

The workshop planners asked for presentations that would be provocative. Therefore, due to our successful use of the bogie at the FOIL, here is Provocative Statement 1:

1. The "breakaway" bogie should be mandated for certification testing of breakaway sign and luminaire supports.

This mandate would have the benefits of lower cost and greater repeatability of results. Results would be more repeatable because of:

- Precise control of vehicle weight.
- Identical frontal crash characteristics.

Due to the success with bogies at the FOIL, FHWA researchers have proposed plans to design and validate a series of bogies, each custom tailored to test a specific type of roadside hardware. The status of this bogie development program is as follows:

- Breakaway Bogie (Presently Validated and In-Service)
- Base Bending Bogie (Preliminary Design Underway)
- Crash Cushion Bogie (Development on Hold within FHWA R&D)
- Guardrail Bogie (Planning Stage Only)
- Rigid Barrier Bogie (Planning Stage Only)

The above proposals for several new types of bogies at the FOIL lead to Provocative Statement 2:

2. Other surrogate vehicles (bogies) should be mandated for certification testing of roadside safety hardware as they become available. A procedure should be established for the acceptance of new surrogate test devices.

During the series of 44 bogie tests on breakaway supports conducted at FOIL we learned that some test setup parameters greatly affect the test results and the reporting of results. For example, variations in the mounting bolt torque for transformer bases, the clamping bolt torque for slip bases and the mounting circle diameter for transformer bases had a substantial effect on breakaway energy required, and thus the change in velocity of the bogie.

Additionally, the 1985 AASHTO specifications for the testing of breakaway supports require that the stubs of the breakaway devices have no substantial portions extending more than four inches above the ground. In many cases it is difficult to judge what constitutes a "substantial" stub of material, yet this criterion can cause a device to pass or fail. "Substantial" should be defined such that a testing agency can determine a pass or fail condition accurately.

The above observations during our bogie tests of breakaway luminaries lead to Provocative Statement 3:

3. Mounting bolt torques for breakaway devices that are being crash tested should be precisely defined, either by quantifying the torque or specifying acceptable torque ranges. The mounting bolt torques actually used should be reported. Transformer bases should be tested using the maximum bolt circle diameter. The term "substantial" in the AASHTO stub height criterion should be defined or quantified.

Just as the bolt torque and bolt circle requirements for breakaway supports need to be specified in crash test setup procedures, other roadside safety hardware may need more detailed setup procedures for crash testing. This leads to Provocative Statement 4:

4. A procedure should be defined for specifying new test setup requirements as new knowledge regarding the effect of these setup requirements on test results is determined from other new surrogate test vehicles as they are brought on line.

G. Comments on NCHRP Report 230 Related to In-Service Evaluations

By: Dave Woodham, Colorado Department of Transportation

The Colorado Department of Highways has just completed a four-year in- service evaluation of three highway safety appurtenances. Covered in this study were the SERB and Modified Thriebeam guardrails and the Colorado Type 3F Median Barrier End Treatment. In addition, Colorado has an on-going study which is monitoring 2300 feet of IBC Median Barrier installed in the Denver area.

It sometimes seems like a big step to go from full-scale crash testing to the "real world" where every car that comes along is not a Honda Civic or a Plymouth Fury. The possible range of vehicles, their modifications, and the range of skill with which they are driven make interpretations of the collected data difficult. In addition to this, most of the "high performance" barriers are installed in areas which are very different from that of the test site. As an example, the location of the SERB guardrail in Colorado is near the bottom of a 1.9 mile long grade of 6.2% and on the outside of a left curve of 760 foot radius.

The problems associated with in-service evaluations begin right after the device has successfully completed its crash testing program. In most cases, highway designers are reluctant to specify large numbers of a safety appurtenance which has no maintenance or repair history. In addition, what are the liability issues introduced by not specifying the "tried-and-true" device? On the other hand, it is necessary to have a large enough sample size to get statistically valid data and to draw some sort of conclusions from it. Colorado's SERB installation has been in service since the fall of 1983 (almost five years now). To date, only two accidents have been reported.

Even if several of a new appurtenance are installed in areas with a high probability of an impact, what seems to happen is that a certain number of the impacts which occur are not "typical." For example, the direction of the impact was exactly opposite to that for which the appurtenance was designed, or a piece of farm machinery hits the device, or a vehicle rolls over onto the appurtenance. It is not that we can't learn anything from these types of impacts, just that care must be taken not to draw any general conclusions from them.

Another problem with data collection is the unreported hit. The closer the barrier approaches "ideal" performance, i.e., safely redirecting the vehicle, no snagging, minimizing exit angles, etc., the more impacts seem to go unreported. It is often possible to get some information on the impact based on skid marks or vehicle debris but usually the data is sketchy at best. Some of these incidents are caused by drunk drivers, uninsured motorists, and drivers whose licenses are under suspension. Their last thought is to call the police because they scraped a guardrail. It is also possible that many other motorists simply want to avoid the "hassle" of a police investigation as long as damage to their vehicle is relatively minor. This happened several times during a study of the SERB and Modified Thriebeam guardrails where evidence of heavy impacts appeared on the guardrails but no accident reports were ever filed.

Once appurtenances have been damaged and require repair, several other problems often show up. If a highway safety appurtenance contains any components which are not "off-the-shelf," there are often delays in getting the device repaired. It would seem that the obvious answer is to stockpile spare parts, but maintenance is reluctant, and probably justifiably so, to buy special parts for one or two appurtenances on the chance they might be needed. An example of this is the SERB guardrail. An accident occurred in July of 1986, but due to a combination of problems and delays, the repairs were not completed until almost 2 years later.

Another problem is with the drawings that maintenance uses to rebuild an end treatment or guardrail. More often than not, the copy they have is a third generation copy of plans which were crowded and confusing in the original. The use of isometric sketches, still photography or video seem to me to be a more natural method of communicating this type of information to these people. The Colorado Department of Highways is planning on making some video tapes which provide step-by-step instruction for repairing specific appurtenances. Perhaps every new appurtenance should come out of the testing program with a repair video. This is a serious problem as systems are becoming more and more complex. The addition or absence of a washer in a critical connection or a weakening slit facing the wrong direction can have serious results.

Another related problem which should be discussed is that of modifications. Often times construction or maintenance people see a better way to do things. What may seem to be a minor modification to an appurtenance could lead to poor performance. It may be possible during the testing phase of an appurtenance to identify those areas where details are very crucial and others where they are somewhat more forgiving.

In conclusion, it seems there are many reasons why an in-service evaluation cannot possibly draw any conclusions, but these studies still provide the best way we know of providing important information about a highway safety appurtenance under actual conditions. This information is invaluable for highway designers and therefore needs to be collected in a rigorous, scientific manner.

H. NCHRP Report 230–The Industry Perspective

By: **Owen Denman, Energy Absorption Systems, Inc.**

The National Cooperative Highway Research Program Report Number 230 (NCHRP 230) is a widely used document that gives guidance to those involved with researching, developing, evaluating and specifying highway safety appurtenances. While this document has been in use since 1981, it is currently being revised under the direction of NCHRP. The developer of the revised document will receive input from the various perspectives presented at this workshop. This presentation is presented from an industry perspective.

Some changes to improve NCHRP Report 230 from an industry perspective have been identified and can be broken down into five issues as follows:

- Interpretation
- Appurtenance application
- Occupant risk factors
- Vehicle characteristics
- Acceptance/Enforcement by appropriate agency

The interpretation issue involves developing a document that can be easily/clearly understood by the user organizations. Some are very skilled in understanding risk assessment, theoretical performance and testing specifications, while others may not have this expertise. Therefore, the document should be kept as simple as possible to allow user acceptance and proper use while being detailed enough to ensure that technical compliance is being met.

The appurtenance application issue is an area that is not clearly defined in NCHRP Report 230. General appurtenance categories (i.e., longitudinal barriers, terminals, crash cushions, etc.), test conditions, and evaluation criteria are described without guidance relative to where the appurtenances are to be used. As an example, a longitudinal barrier end may be terminated with a terminal section or with a crash cushion. The performance requirements for the selected system may be affected by where it is to be applied (i.e., edge of road, narrow median, wide median, for attachment to a rigid/semi-rigid/non-rigid longitudinal barrier, etc.). If a terminal is used in a narrow median application, it would not be appropriate to allow the vehicle to "gate" through the system and create a hazard in opposing traffic lanes. In wide median or roadside applications with appropriate clear zones, gating may be allowed.

The type of longitudinal barrier that the terminal protects also is an important application issue. If the terminal is attached to a rigid barrier, measures should be taken to ensure that proper transition between the terminal and the longitudinal barrier are implemented to obtain proper performance. Otherwise, the vehicle may penetrate the terminal excessively and snag or impale itself on the end of the rigid barrier.

The use of non-redirective terminals such as inertial barriers present another application issue. The inertial barrier systems can be effective appurtenances when applied properly. However, it should be understood that these systems do not have redirective capacities and thus should not be used where there are modest probabilities of angled impacts into the sides of the system.

The application issue can be addressed in the new criteria by using flowcharts (Figure 3) or other decision matrices that instruct the document user about the proper testing and evaluation requirements for appurtenances.

The occupant risk factor issue centers around the topic of "design" and "limit" values when evaluating systems. The concept of having a design (desirable) value and limit (upper maximum) value for occupant risk factors is not new. These concepts have been in existence since the early 1970's (i.e., in NCHRP Reports 118 and 153). While NCHRP Report 230 was new in introducing the concepts of "occupant impact velocities" and "ridedown g levels" the concepts of desired and maximum acceptable levels were rightfully retained. This concept challenges the research and development professionals to advance the state-of-the-art performance toward the desired values while allowing acceptance of current state-of- the-art appurtenances to improve roadway safety conditions for the motoring public.

The Federal Highway Administration (FHWA) recently suggested that only appurtenances passing the "desired" occupant risk values should be accepted for use. This could have an adverse effect on new developments to improve the state-of-the-art and in the acceptance of current state- of-the-art systems. Therefore, the new criteria should retain the desired and maximum limits for occupant risk evaluations similar to those used in NCHRP Report 230.

The vehicle characteristics issue that should be addressed in the new criteria center around the 4500S vehicle in NCHRP Report 230. Vehicles in this weight range that are less than 6 years old are most difficult to locate. In the late 1970's and on into the 1980's, the weight of the larger, luxury vehicles became substantially less to provide better fuel economy. As a result, most of the current luxury vehicles are in the 3600 to 4000 pound weight range.

Current vehicles also have other characteristic differences such as the predominance of front wheel drive systems and changes to the bumper and center-of-mass height values. These characteristics should be taken into account when selecting the standard vehicle parameters in the new criteria.

PROPOSED APPURTENANCE EVALUATION FLOWCHART

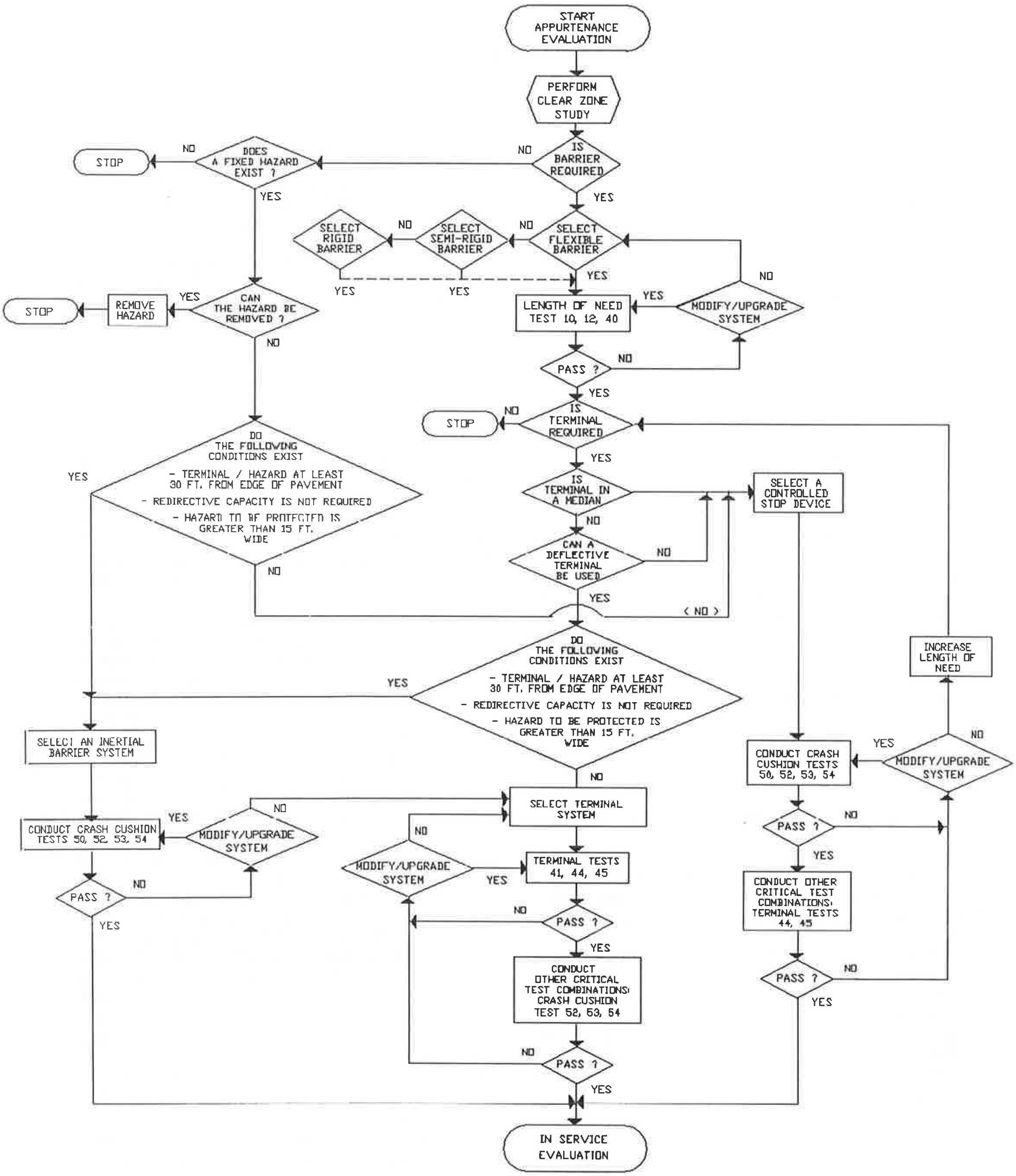


Figure 3

The acceptance/enforcement issue is not necessarily a topic that can be written into the new criteria. This issue deals more with coordination between the National Cooperative Highway Research Program, the Federal Highway Administration and the American Association of State Highway and Transportation Officials (AASHTO). There should be agreement between these groups prior to the completion of the new criteria to ensure the document will be accepted by all of the advisory, funding and enforcement agencies.

The major problem with NCHRP Report 230 is that there is not complete acceptance of the testing and evaluation guidelines set forth in the document. One agency or state will accept part of the criteria but not all, while another agency will accept another part. Thus, instead of having a uniform application of guidelines, there may be 50 or more variations that must be taken into account when new appurtenance systems are being developed. The result is confusion and a lack of directed effort to advance the state-of-the-art in these lifesaving devices.

Another concern with the acceptance/enforcement issue results from many agencies requiring that appurtenance systems be tested and/or perform in conformance to the guidelines set forth in NCHRP Report 230. The exact wording of the state specifications are vague. The problem is insufficient enforcement of the specifications due to a lack of understanding (by the state agencies) of the consequences of not using systems that meet the criteria. A desire for competition and alternate bids frequently overshadows performance to acceptable standards in a lifesaving safety appurtenance.

In summary, a revision of NCHRP Report 230 that addresses the issues of interpretation simplicity, evaluation of performance based on appurtenance application, maintaining "desired" and "maximum" occupant risk philosophy, updating vehicle characteristics and gaining prior acceptance of appropriate agencies will provide improved guidance to research, development, evaluation and specification professionals. This will result in the development and implementation of improved systems and safer roads for the motoring public.

PART 3 DISCUSSION TOPICS

The workshop attendees were split up into the four discussion groups shown in Table 2 with color coding and nicknames to highlight their identities.

Table 2 Discussion Groups

Bogie Team (Green)	Dummy Team (Brown)
John Hinch,Ldr.	Jarvis Michie,Ldr.
Bronstad	Campbell
Copelan	Denman
Hasbrouck	Glauz
Hatton	Lisle
Hunter	Marek
Johnson	Peek
Mak	Sicking
Marcel	Yang
Marlow	
Shearin	
Tye	
Air Bag Team (Blue)	**Work Zone Team (Yellow)**
Hayes Ross,Ldr.	John Carney,Ldr.
Bishop	Anderson
Dinitz	Durkos
Duckett	Krage
Hancock	McCullagh
Hargrave	Melvin
Hedgecock	Pivetti
Marley	Post
Turbell	Stoughton
	Taylor
	Woodham

It was suggested that the discussion groups follow the procedures below:

1. The pre-appointed discussion leader was to select a secretary to keep notes that could be used by the discussion leader for his summary to the entire workshop gathering the next day.
2. The discussion leader was to select a timekeeper who would allow 15 minutes for each of the fifteen topics except for deviations approved by the leader.
3. The discussion leaders were free to modify the order of the discussion topics, to add topics and to use their own leadership style in order to promote discussion.

The discussion topics are given in Table 3. All four groups used the same list of discussion topics.

Table 3 Discussion Topics

1. Purpose of the Guidelines

Should the purpose be studied and redefined?

a. Should the guidelines be relatively permissive to facilitate research studies?
b. Should they be tightly written as a certification document so that it can be directly referenced in purchase specifications?
c. Should both approaches be incorporated?

2. Updating the Test Matrix

Should multiple performance levels be added to the required test matrix?

a. Should the new AASHTO bridge rail test matrix be adopted or should the test matrix be developed from scratch?
b. Should all longitudinal barriers have the same test matrix?
c. How great is the need for safety features designed specifically for the secondary road system?
d. Should test conditions be representative of real world accidents or designed to reach imminent failure of the test barriers?
e. Should the impact angle be studied? Should it vary with performance level?
f. Should the location of the impact point be strictly defined?

Should work zone barriers be included in the required test matrix?

a. Should they have a test matrix developed independently from permanent barriers and based on work site conditions?
b. How will "work zone" or "temporary" barriers be defined?
c. What safety devices other than longitudinal barriers should be included in a work zone barrier test matrix?

Should passenger vehicles be studied to select new standard vehicles for the test matrix?

a. What vehicle should replace the 4500-lb. car?
b. Should sub-1800-lb. vehicles be specified or made optional?

Table 3 Discussion Topics (*Continued*)

c. If pickups are used to replace the 4500-lb. car, should heavyweight passenger cars (say 3300-3500 lbs.) also be required?
d. Should specific make(s) and model(s) of cars be specified with frequent updates?
e. Should the vehicle chosen (pickup, for example) be representative of a large population of vehicles or chosen to obtain a desired Impact Severity level?

Should detailed office studies be performed to select heavy vehicles and miscellaneous vehicles for the test matrix?

a. What vehicles should be included in a non-required supplemental test matrix (vans, buses, 80,000 lb. trucks, motorcycles for example)?
b. What type of cargo should be required on heavy vehicles and how should it be anchored?
c. Should any safety features other than longitudinal barriers be included in the test matrices for heavy vehicles and miscellaneous vehicles?
d. Should the 18 kip and 50 kip trucks be more fully justified?

Should safety features be tested or evaluated for their ability to handle non-tracking accidents (includes side impacts)?

a. Should tests be proposed?
b. Should computer simulations or other surrogate test methods be used?
c. Which safety features should be evaluated for non-tracking accidents?
d. What passenger restraint conditions should be used for non-tracking tests?

Should new safety features be added to the test matrix?

a. Truck mounted attenuators?
b. Call boxes, mail boxes?
c. Drainage structures?
d. Ditches and other terrain features?
e. Curbs, berms, drop-offs?
f. Others?
g. Should guardrail terminals and crash cushions have the same required tests?

3. Updating Performance Criteria and Human Tolerance Considerations

Should dummies be used to evaluate any or all crash tests?

a. Should they be restrained?
b. Should air bags be used?
c. Should their kinematics be recorded with high speed cameras?
d. Should side impact dummies be specified, and if so, which one?

Should the flail space criteria be studied and revised?

a. Should the criteria be based on unrestrained or restrained passengers?
b. Should human tolerance studies be reviewed to reaffirm or revise present limits on occupant impact velocity and ridedown acceleration?
c. Should the suggested safety factors applied to occupant impact velocity and ridedown acceleration become mandatory?

Should all performance criteria be reviewed and revised?

a. Should each performance level have the same or different standards of success?
b. Should work zone barrier performance standards be different when workers are protected by the barrier?
c. Should passenger compartment intrusion be defined more precisely?
d. Should rollover of the test vehicle be permitted in any test?
e. How should loss of cargo and jackknifing be evaluated?
f. Are the present vehicle trajectory criteria too restrictive?
g. What evaluation factors should be used for tests of curbs, ditches, TMA's, drainage structures and other safety features that may be added to the guidelines?

4. Updating Data Collection and Analysis

Should the section on data collection and analysis be reviewed and revised?

a. Should a standard method of data collection and storage be required?
b. Should a standard method of data analysis and presentation be required?
c. How much instrumentation is essential to evaluate the tests properly?

5. Inclusion of Surrogate Test Vehicles, Computer Simulations, Etc.

Should surrogate vehicles be studied and standards for their use be added to the guidelines?

a. Which of bogies, pendulums, scale models and computer simulations should be included?

Table 3 Discussion Topics (*Continued*)

b. Should any of these be permitted for use in acceptance tests?

c. Should any of these be permitted as acceptance substitutes on a supplemental test matrix?

d. Should standards for the validation of surrogate vehicles be included in the guidelines?

e. What are the limits of use of thc various surrogate test vehicles?

f. Should surrogate vehicles (bogies, for example) be standardized or custom made by each testing agency?

g. Should proprietary computer programs (programs not available to any agency outside the testing agency) be allowed for use in acceptance tests or setting conditions for acceptance tests?

6. In-Service Evaluation

Should the section in NCHRP Report 230 on in-service evaluation be reviewed and revised?

a. Is there any way to encourage more use of this section?

b. Should FHWA provide more funding and influence?

7. Industry Perspective

Should more details be included on the acceptance of proprietary safety features?

a. In a series of developmental tests leading toward certification, what changes in the design can be made between the first and last test without retesting?

b. After acceptance of a specific feature, what plans, specifications, etc. should be required, who should have them on file, who should have access to them, and how should minor and major changes to these on-file plans and specifications be revealed to user agencies?

c. Should proprietary products tested under old NCHRP Report 230 be requalified under revised NCHRP Report 230?

d. Should certification be transferable between states and/or FHWA?

8. Other Concerns

Should the standard soil specifications be reviewed and revised?

a. Is the current standard weak soil (S2) too conservative?

b. Is S2 non-representative?

c. What tests, if any, should be required in frozen or saturated soils?

PART 4 SUMMARIES OF BREAK-OUT GROUP DISCUSSIONS

The comments from all four discussion groups are listed under each of the 15 main discussion topics:

1. Should the purpose be studied and redefined?

Green Team

We felt the document should be developed into an acceptance type guideline. We also felt it would be used as such even if it wasn't intended to be; thus, it should be designed with this in mind. The R&D approach should be addressed in the commentary section of the document and should give some guidance on how to test new types of devices as they come on line. The potential use of a test which does meet the test criteria perfectly would also be of interest to both the testing houses and the contractors. From a research point of view, there is almost always something to be learned from a test.

Brown Team

The document will be used both for research studies and for certification testing; recommend that these aspects be in different sections of the document.

Blue Team

The document will be used for certification regardless of how it is written - witness Report 230. It should be rather rigid for well-established safety features such as longitudinal barriers, crash cushions, etc. It should be flexible enough to accommodate possible future changes in test conditions (vehicles, risk values). It should be written with the practicing highway engineer in mind since he or she will be making increased use of the document.

We recommend establishment of a "panel of experts" to periodically review items such as test vehicles and performance criteria.

Group Priority: High

Yellow Team

The purpose should be studied but probably not redefined. The main purpose is to present uniform procedures for crash testing and in- service evaluation of safety appurtenances. It should have elements of both research guidelines and of certification specifications for purchase documents to satisfy the needs of manufacturers and government.

2. Should multiple performance levels be added to the required test matrix?

Green Team

We agreed with all the groups that the multiple performance level approach developed by AASHTO should be adopted by the new 230 document. We felt that this matrix could be used almost as is for all longitudinal barriers. The impact angle and impact location should be looked at closely, with both of these items needing some discussion in the commentary. We also thought there was a need for a very low performance level rail and terminal for deployment in low speed urban locations (35 to 40 mph). We agreed that most of the time actual test conditions should be linked to actual accidents occurring on the highway system.

Brown Team

There was concern with potential tort problems for states in implementing a multiple performance level system. All barriers should be tested to conditions representative of real world accidents, and within those conditions select critical impact parameters based on each barrier type (i.e., for post and beam systems, consider snagging problems).

Blue Team

The MPL concept should be considered but not equally for all features, i.e., breakaway structures or crash cushions may not need MPL.

The MPL criteria should be determined from either:
(a) Results of upcoming NCHRP Project 22-8
(b) Judgment of NCHRP Project 22-7 panel and research team (Note: Scope of 22-7 will not permit research to establish MPL criteria by B/C analysis).

Researchers should carefully examine new proposed bridge rail test matrix and amend it if necessary.

Sign and luminaire supports should be tested for angular impacts.

Group Priority: High

Yellow Team

More study is required before the AASHTO bridge rail test matrix is incorporated in the Report 230 update. All longitudinal barriers should not necessarily have the same test matrix. There is a great need for less expensive safety features for the secondary road system. These roads have a high fatality rate but a low traffic volume which presents cost/benefit difficulties. These tests should be conducted with smaller impact angles than are presently used. The test conditions should be representative of real world accidents. In general, test impact angles should vary with performance level, but should all be less than 25°. The location of the impact point should not be strictly defined; the acceptance agency should play a role; e.g., with Test 54, the nose angle test for crash cushions. The impact point for Test 30 on transitions should be redefined.

3. Should work zone barriers be included in the required test matrix?

Green Team

Work zone barriers need a separate test and evaluation matrix. Low impact angles and high speeds (60 mph) should be considered. Other devices which should be considered include: TMA's, terminals, signing, channelizers. For TMA's, safety evaluation factors may need to be developed for both the vehicle occupant and the worker driving the shadow vehicle. We felt that deflections of the barrier which could endanger the worker should be addressed in the warranting of the actual device for the level of protection required.

Brown Team

Work zone barriers should have a different matrix but there was no consensus as to what it should be other than:

- Not at reduced speed
- Possibly at reduced angle
- Maybe some high angle service level

Blue Team

Independent test standards should be developed for work zone hardware.

Work zone hardware should include: TMA's, signs, end treatments, and channelization devices as well as longitudinal barriers.

Barrier performance should be defined in terms of duration of use at a particular site. Examples include movable or truly portable barriers such as truck mounted longitudinal barriers and barriers for long duration use such as precast concrete barriers.

Group Priority: High

Yellow Team

Work zone barrier test should have special performance level unique features such as lower speeds, lower impact angles, geometric constraints, and the need to protect workers. Work zone or temporary barriers should be defined in terms of how long they will be in place. The work zone barrier test matrix should include longitudinal barriers, end treatments, temporary signs, delineation devices, and truck mounted attenuators.

4. Should passenger vehicles be studied to select new standard vehicles for the test matrix?

Green Team

The pickup is probably a good replacement vehicle for the 4500-lb. test vehicle. We felt that it should be reviewed during the update. We also felt that the current 1800-lb. vehicle was small enough and the need for a micro type vehicle is not needed at this time. As far as an intermediate sized test vehicle, it was felt that it was not needed at this time but some research should be conducted from time to time to insure that it does not become needed. We felt that the same make and model should be used for all acceptance type tests. This removes as much as possible the effect of the vehicle on the outcome of the test. We would recommend that a Task Force be set up to review the selection of the standard test vehicle. Also some basic research should be conducted to explore the effect of using various test vehicles on a given type of hardware.

Brown Team

All vehicles should be representative of a large population of vehicles and, in particular, to ones involved in accidents.

The program should examine a mechanism whereby designated vehicles can be periodically updated.

Blue Team

Selection of a replacement for the 4,500-lb. car must involve careful review and use of new bridge specifications as appropriate. Sub-1,800-lb. vehicles should not be specified; however, they may be included as an option.

Large sedans should be considered in view of their wide use.

Test vehicles should be specified more in terms of vehicle characteristics rather than age or specific model.

All vehicles selected for use in the crash test matrix should be representative of a large population of vehicles.

Group Priority: High

Yellow Team

The 5400-lb. pickup probably should replace the 4500-lb. car in the test matrix. We are not convinced a case has been made for testing with sub-1800-lb. vehicles. Any such inclusion should be well documented. Perhaps heavy weight passenger cars should also be included in the test matrix; a mini-van is a possibility. We do not favor picking specific makes and models of cars for testing. The passenger vehicles chosen should be representatives of their class and surrogates for vehicles below that class.

5. Should detailed office studies be performed to select heavy vehicles and miscellaneous vehicles for the test matrix?

Green Team

The supplemental matrix is needed for longitudinal barriers only. An 80 kip vehicle is needed with both a van type and tanker trailer. Also the 18-and 50-kip trucks should be more justified. Cargo attachment needs to be clearly defined. A discussion on the technique should be made in the commentary.

Brown Team

No safety feature other than longitudinal barriers should be included in the test matrices for heavy and miscellaneous vehicles. The 18- kip and 50-kip trucks should be more fully justified. There was concern with the selection of the 18-kip truck with AASHTO bridge rail test matrix; it needs to be examined. Truck selection should be based on accident statistics. The type and method of cargo tie down needs study.

Blue Team

The 18-kip and 50-kip truck should be studied to more fully justify their use as test vehicles.

Heavy vehicle test matrix should allow flexibility in vehicle selection for specific cases. Supplemental matrices may be one method for providing flexibility.

Group Priority: Medium to High

Yellow Team

The type of cargo used on heavy trucks and the anchorage method for the cargo should mirror real life. In addition to the longitudinal barriers, signs should be tested with trucks because of the high, vulnerable windshields. The 18-kip and 50-kip trucks specified in the AASHTO bridge rail test matrix should be more fully justified before adoption into Report 230.

6. Should safety features be tested or evaluated for their ability to handle nontracking accidents (includes side impacts)?

Green Team

Several general test types could be specified in the commentary section of the update. Also, evaluation techniques will need to be developed for these types of tests where intrusion is likely. Safety features which might be investigated with non-tracking type tests include: attenuators, small signs, luminaires, and other narrow devices. Seat belts should not be used in these type tests.

Brown Team

Results of the FHWA project on side impact accidents and testing should be carefully studied. We do not recommend side impact testing for compliance at this time. The use of computer simulation for these conditions should be explored.

Blue Team

No nontracking tests should be specified at this time; however, this should be a high priority research item.

The need to study the nontracking problem with computer simulations and accident studies as appropriate should be presented.

Group Priority: Low to High

Yellow Team

Supplemental tests rather than required tests should be proposed. Computer simulations and other surrogate test methods could be used. The safety features which should be evaluated for nontracking accidents include longitudinal barriers and curbs. Dummies should be unrestrained in nontracking tests.

7. Should new safety features be added to the test matrix?

Green Team

TMA's, call boxes, and mail boxes should be added to the matrix. The terrain type structures may not be needed in the matrix but some discussion in the commentary should be made on the type of critical tests which should be conducted. A possible generic test could be developed which could be used to evaluate these types of devices.

Brown Team

Include TMA's in the test matrix.

Use the same test matrix for both crash cushions and end terminals but evaluate them with different criteria.

For other potential features, use narrative to describe the method for development of the test matrix.

Blue Team

Some new safety features should be added to the test matrix, including TMA's and call boxes.

The state-of-the-art in design and prior test results should be presented for other safety features, such as drainage structures, ditches, curbs, and berms.

Guardrail terminals and crash cushions should be tested in accordance with their intended purpose.

Group Priority: High

Yellow Team

There was some sentiment for testing TMA's, call boxes, terrain features, curbs, drop-offs, etc., but possibly with different vehicles, e.g., trucks have problems with drop-offs. Guardrail terminals and crash cushions need to be defined, maybe in terms of gating vs. redirecting behavior.

8. Should dummies be used to evaluate any or all crash tests?

Green Team

Dummies are not needed for the acceptance type tests. During R&D type tests, use of dummies could become important in understanding occupant injury. During side impact tests the use of a SID should be considered when intrusion into the occupant compartment is likely. Also the use of an uninstrumented dummy during tests with tall rails (those taller than the bottom of the window) should be considered to investigate the interaction between the dummy and the rail if the head and shoulder become partially ejected.

Brown Team

Use of uninstrumented dummies may be warranted. On-board cameras are not necessary. Use of side impact dummies is not recommended. There was no consensus on restraint condition.

Blue Team

In view of the cost associated with instrumented dummies and the limited applications of dummy data collected to date, instrumented dummies should not be required. Uninstrumented dummies should be used in certification testing. Instrumented dummies should be recommended as a tool for developing a link between vehicle response and occupant risk.

Group Priority: Medium to High

Yellow Team

Dummies should be used in some tests, but should be uninstrumented when used. They should not be restrained, nor should air bags be used because it will be several years before a large majority of vehicles have them. When appropriate, dummy kinematics should be recorded with high speed cameras. Side impact dummies are still in the developmental stage and should not be used.

9. Should the flail space criteria be studied and revised?

Green Team

We think the flail space model for analyzing occupant injury should be maintained but reviewed. The criteria should continue to use flail distances which are compatible with unrestrained passengers. Human tolerances also should be reviewed to insure that they are still current. We felt that the safety factors should become mandatory but the actual value should be reviewed. The 40 fps criterion should be reviewed. It was pointed out that 40 fps is equivalent to jumping off a 25 ft. platform.

Brown Team

Provide assessment criteria for both restrained and unrestrained occupants and let FHWA and/or the states decide on the appropriate approach.

The suggested safety factors in Report 230 for occupant impact velocity and ride down acceleration should not become mandatory.

The NCHRP Report 230 update contractor should review human tolerance literature.

Blue Team

Potential new occupant risk models should be reviewed and compared to existing models.

Occupant risk evaluation should be re-evaluated for restrained and unrestrained occupants. The safety factors now in Report 230 should be termed "desirable" and the maximum limits should be termed "required."

Group Priority: High

Yellow Team

The flail space criteria should be based on unrestrained passengers for now, but maybe restrained in the near future. There could be two sets of criteria in the future as an option for the acceptance agency. Human tolerance studies should be reviewed for possible revision of occupant risk requirements. The suggested safety factors for occupant impact velocity and ridedown acceleration should not be made mandatory. Acceptance agencies should have the flexibility to choose safety factory.

10. Should all performance criteria be reviewed and revised?

Green Team

We felt that all performance levels should use similar standards for evaluation. Work zone barriers should use the same criteria as other barriers. When workers are present then a higher performance rail should be warranted. Passenger compartment intrusion needs to be defined very carefully. There are gross differences between a rail spearing and slight wrinkling in the vehicle floor structure, and guidance is needed in this area. Roll-over should be allowed for heavy vehicles as long as the vehicle is contained. The loss of cargo and jackknifing need to be reviewed and discussed in the commentary section of the update. The current trajectory requirements are too restrictive and need to be reviewed.

Weighting of the various factors could be considered. We thought that intrusion of the passenger compartment is more important in the evaluation of the test than post impact trajectory. We ranked the following 5 criteria on a scale of 1 to 5.

- Intrusion 5.0
- Flail Space 4.5
- Roll-over 3.5
- Structural Adequacy 4.5
- Post Impact Trajectory 2.0

The evaluation of roadside devices which generate vertical motions, such as ditches, could make use of a vertical flail space model where the vertical accelerometers are processed to obtain the delta v and ride down acceleration.

Brown Team

There is a need to quantify the passenger compartment intrusion.

There is a need to study the criticality of rollover and possibly to soften restrictions in some cases.

The protection of truck drivers is probably beyond the current state- of-the-art.

The importance of vehicle trajectory should be studied; maybe the priority of the factor should be reduced.

The ranking of evaluation factors is recommended.

Blue Team

All performance levels should have the same standards of success.

Work zone barrier evaluation standards should not depend on where the barrier is used.

Passenger compartment intrusion should be defined more precisely.

The severity of rollover should be evaluated to determine if it can be considered permissible under some circumstances.

Current post-impact trajectory criteria are too restrictive.

Test evaluation factors should be weighted.

Overturn is the primary concern for evaluating geometric features.

Group Priority: Medium to High

Yellow Team

High performance level barriers may need different roll-over criteria than other performance levels. Better warrants are needed for work zone barriers where workers are protected by the barriers. A slight rippling of the vehicle floor should not be considered a violation of the passenger compartment intrusion standard. In some tests, possibly trucks should be allowed to roll-over without failing the tests, but cars should not be allowed to roll-over. The evaluation criteria "I" for vehicle trajectory are unreasonable. Tests procedures for TMA's should consider the weight of the shadow vehicle, whether the shadow vehicle is in gear or braked, acceptable roll ahead distance, etc. The various evaluation factors should not be weighted.

11. Should the section on data collection and analysis be reviewed and revised?

Green Team

Standard methods should be used for all data collection systems. They do not all have to be the same but should use standard techniques. The amount of instrumentation to be used in a crash test should be reviewed. Digital data collection systems should be considered in new data collection systems.

Brown Team

Further study should be given to instrumentation requirements.

There was a concern that test results be reported in a standard format and be complete to aid in comparison between designs.

Blue Team

Data collection and analysis requirements should be carefully reviewed.

Group priority: Medium to High

Yellow Team

A standard method of data collection and storage and a standard method of data analysis and presentation should be required. Redundancy of instrumentation is needed.

12. Should surrogate vehicles be studied and standards for their use be added to the guidelines?

Green Team

Surrogate vehicles should be included in the new 230. Devices similar to the FOIL bogie and pendulum should be considered as replacement test devices. We felt that the FOIL bogie should be used as an acceptance type vehicle, and should be considered as a mandatory test device for testing short duration breakaway type devices. A discussion should be included in the commentary to set up a technique for validation of three surrogate vehicles. Possibly a detailed process should be developed for this validation. Custom test devices should be allowed since several are now in existence, as long as they are validated. The process for extrapolating the performance of 20 mph breakway hardware to predict what will happen at 60 mph should be reviewed and incorporated in the new document if found to be acceptable.

Brown Team

Include pendulum/bogie tests as acceptable alternatives to substitute for full scale tests when appropriate.

Bogie vehicles should be updated to be representative of the current selected vehicle (i.e., stay within the 6-year limit).

Proprietary computer programs should not be allowed for use in acceptance tests.

Blue Team

Bogies and pendulums should be included in the testing guidelines for breakaway devices only.

Scale models and computer simulations should be included as R & D tools only.

Bogie vehicles should be considered for inclusion as acceptable substitutes for the supplemental test matrix.

Standards for validation and calibration of surrogate vehicles should be included in the guidelines.

No proprietary computer programs should be used to establish test conditions for acceptance tests, and no computer simulations should be used in lieu of crash testing.

Group Priority: High

Yellow Team

Scale models and computer simulations should be used for R & D tools. Bogies and pendulums should be permitted for use in acceptance tests and tests in the supplemental test matrix. Standards for the validation of surrogate vehicles should be included in the guidelines. Surrogate test vehicles should only be used within the limits of their validation. These surrogate vehicles do not need to be standardized; any design should be acceptable as long as it meets performance standards. Proprietary computer programs should not be allowed for use in acceptance tests or in setting conditions for acceptance tests.

13. Should the section in NCHRP Report 230 on in-service evaluation be reviewed and revised?

Green Team

In-service evaluation is important and an effort should be made to encourage more of it. FHWA and/or SHRP are possible sources for funding.

Brown Team

FHWA is the only means to get consistency in this area. This area is important; methods to acquire in-service information should be explored.

Blue Team

Recommendations for in-service evaluation should be reviewed and revised.

Group Priority: Low

Yellow Team

More guidance for in-service evaluation is needed in the appendix. More new money should be provided by FHWA to encourage states to participate.

14. Should more details be included on the acceptance of proprietary safety features?

Green Team

We felt that all devices should be documented completely. Extreme care must be taken when making changes in a design during its development. At the minimum, all changes should be documented clearly as the changes are made and supplied to the approving agency.

Brown team

As a minimum, any design changes should be reported.

Items b and d are outside the scope of the Report 230 Update.

Blue Team

This topic is outside the scope of the document.

Group Priority: Very low

Yellow Team

An audit trail should be provided to document what was tested in each test. The acceptance agency could then decide whether any changes in design were significant enough to require retesting. FHWA should keep the plans of the accepted proprietary device on file. The acceptance agency must decide whether proprietary products tested under NCHRP Report 230 should be retested under the Report 230 update. They also must decide whether certification by another agency is transferable.

15. Should the standard soil specifications be reviewed and revised?

Green Team

The weak soil needs to be specified more clearly. A PI limit is needed. Also, some research should be conducted to insure that this soil is representative of the weaker soils in use around the nation's highways.

Brown Team

This topic needs further study.

Blue Team

This is an important issue that should be carefully studied.

Group Priority: High

Yellow Team

The weak soil (S2) is too conservative and non-representative. The strong soil (S1) specification is satisfactory.

16. Added issues.

Green Team

It was felt that the new document should be in a loose leaf 3-ring binder format. This will allow for easier updates as they become available.

PART 5 PRIORITIZATION OF MAJOR ISSUES

The fifteen issues in the discussion topics were repeated on a rating sheet. Each attendee was asked to rank five issues H for high priority, five issues M for medium priority, and five issues L for low priority. The sheets were tallied by giving a weight of 3 to each H, a weight of 2 to each M, and a weight of 1 to each L, then by summing the weighted values for each issue. Thus, the highest total number represented the issue considered by workshop attendees to have the highest priority for study and revision in the update of NCHRP Report 230. Almost one-fourth of the attendees were from the California Department of Transportation, so their rankings were first compiled separately, then combined with the others. As a matter of interest, the rankings of other sub- groups were tallied. Of course, all the rankings are only a general indication of the views of the roadside safety community because the attendees did not necessarily represent government, industry, university, etc., viewpoints proportionately and some attendees were much longer on experience in the field than others. A few attendees did not split their rankings into five H's, five M's, and five L's which affects the rankings slightly. Nevertheless, some issues were clearly deemed more important than others.

Table 4 Prioritization of Issues

Issues	Safety Device Manufacturers	Private Companies & Consultants	Universities	Caltrans	Other State DOTs	FHWA	Total Points All Attendees	Overall Ranking of Issues
1. Redefine purpose	9	24	10	21	*10	7	81	8/9
2. Add multiple performance levels	*13	*30	*18	*24	* 9	*9	*103	2
3. Add work zone barriers	*15	*31	*15	*23	*12	*9	*105	1
4. Select new passenger vehicles	*15	*26	14	*23	*11	7	*96	3
5. Do studies to select heavy vehicles	5	20	10	17	7	5	64	12
6. Evaluate non-tracking vehicle impacts	7	12	7	11	4	4	45	14
7. Add new safety devices to test matrix	12	*25	*15	21	9	*9	*91	5
8. Evaluate tests with dummies	5	13	6	11	5	3	43	15
9. Revise flail space criteria	10	23	15	17	9	8	82	7
10. Revise performance criteria	*13	*23	*15	*23	9	*8	*93	4
11. Revise data collection & analysis procedures	6	18	12	18	7	7	68	11
12. Add surrogate vehicle tests and standards	*13	24	10	*24	*10	*8	89	6
13. Revise in-service evaluation procedure	12	23	11	13	9	3	71	10
14. Add acceptance details for proprietary features	8	13	6	15	5	4	51	13
15. Revise soil specifications	7	22	*16	19	9	8	81	8/9

*Five highest ranked issues in each column with ranking by total group used to select top five from ties within a column. Total rank sheets = 38

PART 6 WORKSHOP SUMMARY

The presentations and the discussion summaries clearly show that almost every section of NCHRP Report 230 needs review and revision. In addition, several new sections need to be added to incorporate new types of safety devices and to reflect changes and improvements in the technology. There was diversity of opinion on many issues which will take consumate skills on the part of the NCHRP researchers to fashion a consensus update document acceptable to all. Despite some differences of opinion, the workshop attendees showed rather clear preferences for some of the 15 discussion topics. These are the ones that should be given the most attention by the NCHRP researchers. The top five in order of importance were:

1. To add guidelines for the testing of work zone barriers.
2. To include multiple performance levels in the test matrix.
3. To study carefully the passenger vehicle type and weight selected to replace the current vehicle types.
4. To review and revise the performance criteria.
5. To add test guidelines for types of safety features not presently covered in NCHRP Report 230.

At the bottom of the list were topics including revisions in dummy requirements, procedures to evaluate non-tracking vehicle impacts, and acceptance details for proprietary features among others. Even though the rankings were broken down by agency/business type, the priorities were quite consistent across all groups.

It should be emphasized that the workshop attendees were asked to give five topics low ratings. Therefore, it does not mean that these topics were of no interest, only that they should receive less emphasis than some more critical issues. For example, the three lowest ranked issues mentioned above received almost no high priority votes but they all received several medium priority votes.

It was hoped that even though attendees did not arrive or even leave the workshop with opinions fully formed on each issue, that this short intense discussion would start the roadside safety community thinking about the update.

It is hoped that as their mental gears shift into high, workshop attendees will feed additional comments to the NCHRP update researchers in the coming year, and be fully primed by the time they are invited to review the draft version of the updated guidelines. Meanwhile, the NCHRP researchers have ample ideas and opinions from this workshop to begin work on the update.

APPENDIX A

NCHRP Report 230 - Chapters 1, 2 and 3

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-s^2								
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 θ 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.

APPENDIX B

Workshop Attendees

ANDERSON, Howard L., Consultant, Carson City, Nevada

BARTELL, Charles, Division of Traffic Engineering, California Department of Transportation, Sacramento, California

BISHOP, Ralph W., Office of Structure Design, California Department of Transportation, Sacramento, California

BRONSTAD, Maurice, Dynatech Engineering, San Antonio, Texas

CAMPBELL, Fred, Division of Highway Maintenance, California Department of Transportation, Sacramento, California

CARNEY, John F. III, Vanderbilt University, Nashville,Tennessee

COPELAN, Joyce, Division of Traffic Engineering, California Department of Transportation, Sacramento, California

DENMAN, Owen S., Energy Absorption Systems, Inc., Sacramento, California

DINITZ, Arthur M., Transpo Industries, Inc., New Rochelle, New York

DUCKETT, John, Barrier Systems, Inc., Sausalito, California

DURKOS, John, Syro Steel Co., Girard, Ohio

FOLSOM, J. Jay, Transportation Laboratory, California Department of Transportation, Sacramento, California

GLAUZ, Doran, Transportation Laboratory, California Department of Transportation, Sacramento, California

HANCOCK, Kitty, Analysis Group Inc., Rockville, Maryland

HARGRAVE, Martin W., Turner-Fairbank Highway Research Center, Federal Highway Administration, McLean, Virginia.

HASBROUCK, Richard C., Tectonics, San Francisco, California

HATTON, James H., Jr., Geometric and Roadside Design Branch, Federal Highway Administration, Washington, D.C.

HEDGECOCK, Jack, Transportation Laboratory, California Department of Transportation, Sacramento, California

HINCH, John, ENSCO, Springfield, Virginia

HUNTER, William W., Highway Safety Research Center, University of North Carolina, Chapel Hill, North Carolina

JOHNSON, Richard L., Transportation Laboratory, California Department of Transportation, Sacramento, California

KRAGE, William G., Energy Absorption Systems, Inc. Sacramento, California

LISLE, Frank N., NCHRP, Transportation Research Board, Washingon, D.C.

MAK, King K., Texas Transportation Institute, College Station, Texas

MARCEL, William, M/T Advance Engineering, Anaheim, California

MAREK, Mark A., Texas Department of Highways and Public Transportation, Austin, Texas

MARLEY, William G., Jr., North Carolina Department of Transportation, Raleigh, North Carolina

MARLOW, John, Division of Equipment, California Department of Transportation, Sacramento, California

McCULLAGH, Frank, Arizona State University, Tempe, Arizona

MELVIN, John W., Biomedical Science Department, General Motors Research Laboratories, Warren, Michigan

MICHIE, Jarvis, Dynatech Engineering, San Antonio, Texas

PEEK, Steve, Barrier Systems, Inc., Sausalito, California

PIVETTI, Charles, Division of Traffic Engineering, California Department of Transportation, Sacramento, California

POST, Edward R., University of Nebraska, Lincoln, Nebraska

ROSS, Hayes E., Texas Transportation Institute, College Station, Texas

SHEARIN, Ken, Roy Jorgensen Associates, Gaithersburg, Maryland

SICKING, Dean, Texas Transportation Institute, College Station, Texas

STEPHENS, Barry, Energy Absorption Systems, Inc., Sacramento, Calif.

STOUGHTON, Roger L., Transportation Laboratory, California Department of Transportation, Sacramento, California

TAYLOR, Harry W., Office of Highway Safety, Federal Highway Administration, Washington, D.C.

TURBELL, Thomas, Swedish Road and Traffic Research Institute, Linkoping, Sweden

TYE, Edward J., Division of Traffic Engineering, California Department of Transportation, Sacramento, California

WOODHAM, Dave, Colorado Department of Transportation, Denver Colorado

YANG, Ta-Lun, ENSCO, Springfield, Virginia

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