Chapter 5

Evaluation Criteria

5.1 GENERAL

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

Note that the evaluation criteria relate only to the impact performance of the safety feature. Costs,   
aesthetics, maintainability, durability, and other service requirements are not evaluated. It is recognized that user agencies seldom make safety hardware implementation decisions based solely upon impact performance evaluation and that these other factors are also considered.

5.2 EVALUATION FACTORS AND CRITERIA

Recommended impact performance evaluation criteria for safety features are given in Tables 5-1A through 5-1C. Three dynamic performance evaluation factors are given together with recommended evaluation criteria and applicable tests. The factors are: (1) structural adequacy, (2) occupant risk, and (3) post-impact vehicular response.

TABLE 5-1A. Safety Evaluation Guidelines for Structural Adequacy

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| --- | --- | --- |
| **Evaluation**  **Factors** | **Evaluation Criteria** | **Applicable Tests** |
| Structural Adequacy  (see  Section 5.2.1) | A. Test article should contain and redirect the vehicle or bring the vehicle to a controlled stop; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable. | 10, 11, 12, 20, 21, 22, 30a,31a,32a,33a, 34a, 35, 36, 37a, 38a |
| B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding. | 60, 61, 62, 70, 71, 72, 80, 81, 82 |
| C. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle. | 30b, 31b, 32b, 33b, 34b, 37b, 38b, 40, 41, 42, 43, 44, 50, 51, 52, 53, 90, 91 |

a Non-gating terminals and crash cushions

b Gating terminals and crash cushions

TABLE 5-1B. Safety Evaluation Guidelines for Occupant Risk

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Evaluation**  **Factors** | **Evaluation Criteria** | | | | **Applicable Tests** |
| Occupant Risk (see Section 5.2.2) | D. Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present undue hazard to other traffic, pedestrians, or personnel in a work zone.  Deformations of, or intrusions into, the occupant compartment should not exceed limits set forth in Section 5.2.2 and Appendix E. | | | | All |
| E. Detached elements, fragments, or other debris from the test article, or vehicular damage should not block the driver’s vision or otherwise cause the driver to lose control of the vehicle. | | | | 70, 71, 72 |
| F. The vehicle should remain upright during and after collision. The maximum roll and pitch angles are not to exceed 75 degrees. | | | | All except those listed in Criterion G |
| G. It is preferable, although not essential, that the vehicle remain upright during and after collision. | | | | 12, 22 |
| H. Occupant impact velocities (OIV) (see Appendix A, Section A5.2.2 for calculation procedure) should satisfy the following limits: | | | |  |
|  | Occupant Impact Velocity Limits, ft/s (m/s) | | |
| Component | Preferred | Maximum |
| Longitudinal and Lateral | 30 ft/s  (9.1 m/s) | 40 ft/s  (12.2 m/s) | 10, 11, 20, 21, 30, 31, 32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 44, 50, 51, 52, 53, 80, 81, 82, 90, 91 |
| Longitudinal | 10 ft/s  (3.0 m/s) | 16 ft/s  (4.9 m/s) | 60, 61, 62, 70, 71, 72 |
| I. The occupant ridedown acceleration (see Appendix A, Section A5.2.2 for calculation procedure) should satisfy the following limits: | | | |  |
|  | Occupant Ridedown Acceleration Limits (G) | | |
| Component | Preferred | Maximum |
| Longitudinal and Lateral | 15.0 G | 20.49 G | 10, 11, 20, 21, 30, 31, 32, 33, 34, 35, 36, 37, 38, 40, 41, 42, 43, 45, 50, 51, 52, 53, 54, 60, 61, 62, 70, 71, 72, 80, 81, 90, 91 |

TABLE 5-1C. Safety Evaluation Guidelines for Post-Impact Vehicular Response

|  |  |  |
| --- | --- | --- |
| **Evaluation**  **Factors** | **Evaluation Criteria** | **Applicable Tests** |
| Post-Impact Vehicular Response (see Section 5.2.3) | J. through M. Reserved. |  |
| N. Vehicle trajectory behind the test article is acceptable. | 30b, 31b, 32b, 33b, 34b, 37b, 38b, 40, 41, 42, 43, 44, 45, 60,  61, 70, 71, 72, 80,  81, 82, 90, 91 |

a Non-gating terminals and crash cushions

b Gating terminals and crash cushions

5.2.1 STRUCTURAL ADEQUACY

Structural adequacy is generally the first factor to be evaluated, and the safety feature should perform successfully according to the requirements presented in Table 5-1A. Depending on its intended function, the feature may satisfy structural adequacy by redirecting the vehicle, by stopping the vehicle in a controlled manner, or by permitting the vehicle to break through the device.

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

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

Similarly, the distance that an impacting vehicle extends over a barrier or penetrates into the system can affect its impact performance, and this effect is highly dependent upon the placement of other hazards in the vicinity of the barrier. A barrier’s working width is therefore measured and reported as a means for allowing highway designers to avoid placing a barrier too near an obstruction.

5.2.2 OCCUPANT RISK

Risk of occupant injury during impact with a highway safety feature depends, to a large extent, on the crashworthiness of the impacting vehicle. In turn, crashworthiness depends on the design of the occupant compartment, including factors such as structural integrity, padding, restraint system, and so on. However, to the extent possible, the variability of vehicular crashworthiness has been removed from safety feature evaluation. Occupant risk is appraised according to gross vehicular accelerations because they are primarily functions of the safety feature design and the external structural design of the test vehicle. Whereas the highway engineer is ultimately concerned with safety of the vehicle’s occupants, the occupant risk criteria of Table 5-1B should be considered as guidelines for generally acceptable dynamic performance. Note that the optional Criterion J included in NCHRP Report 350 (129) on the use of an instrumented Hybrid III dummy has been deleted from the evaluation criteria.

Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present likelihood to impact with other traffic, pedestrians, or workers in a construction zone if applicable. The degree to which detached elements, fragments, or other debris and the degree to which the displacement of a temporary barrier puts other traffic, pedestrians, and workers at risk in a construction zone will depend on the location of the feature and the impact conditions. A sign that has a tendency for detached elements to scatter over a wide area upon impact may not be the appropriate design for use in the median of divided highway since the detached elements could potentially encroach into opposing traffic lanes. On the other hand, the same sign when struck on the roadside may be of little concern except to occupants of the impacting vehicle. Fragments and debris from an impact with a traffic control device in a construction zone may or may not be a consideration for workers in the work zone, depending on their location relative to the device and the impact conditions. Consequently, it is not practical to establish absolute limits on test article trajectory, debris scatter, or barrier displacement. Rather, it is important to accurately record and report test article trajectory and debris scatter so that a user agency can make an objective assessment of the appropriateness of the safety feature for the intended application.

A clear distinction should be made between: (a) penetration, in which a component of the test article actually penetrates into the occupant compartment; and (b) intrusion or deformation, in which the occupant compartment is deformed and reduced in size, but no actual penetration is observed. No penetration by any element of the test article into the occupant compartment is allowed. As for deformation or intrusion, the extent of deformation varies by area of the vehicle damaged and should be limited as follows:

* Roof ≤ 4.0 in. (102 mm).
* Windshield—no tear of plastic liner and maximum deformation of 3 in. (76 mm).
* Window—no shattering of a side window resulting from direct contact with a structural member of the test article, except for special considerations pertaining to tall, continuous barrier elements discussed below (Note: evaluation of this criteria requires the side windows to be in the up position for testing). In cases where side windows are laminated, the guidelines for windshields will apply.
* and B-pillars—no complete severing of support member and maximum resultant deformation of 5 in. (127 mm). Lateral deformation should be limited to 3 in. (76 mm).
* Wheel/foot well and toe pan areas ≤ 9 in. (229 mm).
* Side front panel (forward of A-pillar) ≤ 12 in. (305 mm).
* Front side door area (above seat) ≤ 9 in. (229 mm).
* Front side door area (below seat) ≤ 12 in. (305 mm).
* Floor pan and transmission tunnel areas ≤ 12 in. (305 mm).

Note that a tear in the windshield plastic liner is not relevant if there is no potential for a test article component to penetrate into the vehicle. For example, a tear produced by a breakaway luminaire pole falling on the vehicle’s roof would not be considered a cause for failing the test. As another example, a continuous, flexible cable element may contact and deform the A-pillar of an impacting vehicle within acceptable limits and cause minor tearing of the windshield’s plastic liner.

During oblique vehicular impacts into tall, flexible cable median barriers, side windows may fracture due to contact with continuous cable elements. Contact with the longitudinal cable elements may also result in localized deformations to the roof’s structural support members (i.e., the A- and/or B-pillars). In such circumstances, the risk of significant intrusion into the occupant compartment and contact between the cable elements and the head of a vehicle occupant is small. The relatively low vehicle decelerations experienced during a vehicular impact with a flexible cable barrier will typically result in only minor lateral movement of the occupant, and the occupant’s head is not expected to be partially ejected outside of a side window. Thus, in these instances, it may be reasonable to relax the side window fracture criteria as long as several conditions are met. First, there should be no demonstrated risk for the ends of rail elements to spear into the occupant compartment. Second, the continuous cable elements should not laterally protrude more than 3 in. (76 mm) into the side window region based on observation of the plastic deformation to the A- and/or B-pillars. Finally, the A- and B-pillars should not be completely severed.

Note that some vehicles now incorporate glued seams on the floor board as well as other areas. In the presence of significant deformation, these bonded seams can separate and create an opening into the occupant compartment. There is no available data to relate occupant injury severity to the opening of seams in the floor pan area. However, it is generally believed that an opening in the occupant compartment by and of itself does not necessarily result in injury to the occupants unless it is accompanied by an object moving toward the occupant. Therefore, a seam separation by itself is not considered a test failure unless (1) a component of the safety device protrudes through the opening or (2) the deformation limits of 12 in. (305 mm) is exceeded.

It is essential that adequate documentation in the form of photographs and measurements of occupant compartment damage be made and reported. Detailed pretest measurements should be made from at least two reference points in the vehicle. Reference points should be widely spaced and selected from locations unlikely to be deformed during the crash test. Interior and exterior photographs, as described in Sections 4.2.1.4 and 4.2.1.6, should be taken prior to the test to permit direct comparisons of before- and after-test conditions.

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

For the majority of tests, a key requirement for occupant risk evaluation is for the impacting vehicle to remain upright during and after the collision. As an indication of vehicle stability, the maximum roll or pitch angle of the vehicle during and after the impact sequence should not exceed 75 degrees. Although it is preferable that all vehicles remain upright, this requirement is not applicable to tests involving the 10000S, 36000V, and 36000T vehicles. See Appendix A, Section A2.2.1, for a discussion of these exceptions.

Occupant risk is also assessed by the response of a hypothetical, unrestrained front seat occupant whose motion relative to the occupant compartment is dependent on vehicular accelerations. The “point mass” occupant is assumed to move through space until striking a hypothetical instrument panel, windshield, or side structure and subsequently is assumed to experience vehicular accelerations perpendicular to the contact surface by remaining in contact with the interior surface. The two performance factors are: (1) the longitudinal and lateral component of occupant velocity at impact with the associated   
interior surface, and (2) the highest lateral and longitudinal component of resultant vehicular acceleration averaged over any 10-ms interval for the collision pulse subsequent to occupant impact with the associated interior surface. These two performance factors are commonly referred to as the occupant impact velocity (OIV) and the ridedown acceleration (RA), respectively. Methods for calculating the occupant impact velocity and ridedown acceleration components are given in Appendix A, Section A5.2.2. Generally, lower values for these factors indicate that the safety features are more forgiving to the occupants of the impacting vehicles. While a surrogate occupant is recommended in tests with all 1100C and some 2270P vehicles, its dynamic and kinematic responses are not required or used in occupant risk assessment. Hypothetical occupant compartment impact velocities and ridedown accelerations are calculated from vehicular accelerations.

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

Recommended limits for occupant impact velocity and ridedown acceleration are given in Table 5-1B. Note that two values are given for each parameter, a “preferred” limit and a “maximum” limit. As implied, it is desirable that the occupant risk indices not exceed the preferred values, and it is recommended that they not exceed the maximum values. Reference should be made to Appendix A, Section A5.2.2, for the rationale used in selecting these values. However, these limits are only recommendations and a user agency may select different occupant risk limits if it so desires.

It should be noted that the measurements are associated with certain uncertainties and tolerances, which may vary among testing agencies. The testing agencies are required to report on these measurement uncertainties and tolerances for consideration by the user agency. Also, there is a degree of precision or rounding errors associated with the measurements. It is recommended that the maximum allowable limits are 40 ft/s (12.2 m/s) for occupant impact velocity and 20.49 G for the ridedown acceleration.

Although not required, testing agencies are encouraged to calculate and report the Theoretical Head Impact Velocity (THIV), the Post-Impact Head Deceleration (PHD), and the Acceleration Severity Index (ASI), as described in Appendix F. The THIV, PHD, and ASI have been adopted by the European Committee for Standardization (CEN) (140–142) as measures of occupant risks. At some time in the future, the U. S. and CEN may develop common impact performance standards for highway features. By calculating and reporting the THIV, PHD, and ASI, a database will be developed from which comparisons can be made relative to the flail space model and from which decisions can be made as to appropriate measures of occupant risk.

5.2.3 POST-IMPACT VEHICULAR RESPONSE

Post-impact vehicular response is a measure of the potential of the vehicle to result in a secondary collision with other vehicles and/or fixed objects, thereby increasing the risk of injury to the occupants of the impacting vehicle and/or other vehicles. Note that NCHRP Report 350 (129) has four evaluation criteria. However, Criteria K, L, and M were found to be non-discriminating and served little purpose. Thus, these evaluation criteria have been deleted, leaving only Criterion N. To avoid confusion and maintain continuity from one set of guidelines to another, the evaluation criteria were not re-lettered.

Penetration of the vehicle behind the test article is unacceptable, except for certain classes of safety features as listed in Criterion “N”, for which vehicular trajectory behind the test article is acceptable. Note that acceptable post-impact behavior may also be achieved if the vehicle is decelerated to a stop while vehicle–barrier contact is maintained, provided all other relevant criteria of Table 5-1C are satisfied. However, it should be kept in mind that, if the barrier is within a lane width of adjacent traffic, the slowed or stopped vehicle may pose risks to oncoming motorists.

Excessive pocketing or snagging of the vehicle and the resulting post-impact trajectory, such as a high vehicular exit angle or spin-out of the vehicle, are not desirable and should be documented. It is preferable that the vehicle be smoothly redirected (for redirective devices), and this is typically indicated when the vehicle leaves the barrier within the “exit box.” The concept of the exit box, adapted directly from the CEN standards, is defined by the initial traffic face of the barrier and a line parallel to the initial traffic face of the barrier, at a distance A plus the width of the vehicle plus 16 percent of the length of the vehicle, starting at the final intersection (break) of the wheel track with the initial traffic face of the barrier for a distance of B. All wheel tracks of the vehicle should not cross the parallel line within the distance B. Figure 5-1 provides a graphic definition of the exit box and defines distances A and B for passenger cars and other vehicles.

Vehicle rebound has been noted for some reusable crash cushions. Given that reusable crash cushions are typically used in narrow gore areas with heavy traffic volume, excessive vehicle rebound could increase the potential for secondary collisions. In order to provide user agencies with the necessary information regarding use and placement of such crash cushions, testing agencies are required to document and report the rebound velocity and point of final rest. The rebound velocity is the velocity of the vehicle center of gravity at the instant any wheel of the vehicle encroaches on the rebound line, which is defined as a line perpendicular to the centerline of the crash cushion and 20 ft (6.0 m) in front of the nose of the crash cushion. Braking of the vehicle should be at least 2 seconds after initial impact and beyond the rebound line. The final resting position of the vehicle should be documented relative to the nose and centerline of the crash cushion and video coverage should continue until the impacting vehicle comes to a complete stop.

During crash tests into flexible barrier systems (e.g., cable barriers), vehicles may travel significantly behind downstream support posts and either ride over or under one or more of the longitudinal cable elements. In such a scenario, there is increased opportunity for a cable element and/or support post to contact and/or become entangled with components of the vehicle guidance system and result in vehicle instability or rollover. For example, when a cable guidance system is used, a steel hub is often attached to the front wheel opposite impact to aid in vehicle guidance prior to impact with the barrier. In a situation where an externally-affixed component of the guidance system (e.g., steel guidance hub protruding from front wheel) clearly interacts with the barrier system and causes an undesirable event (e.g., rollover) to occur as the vehicle is exiting the barrier after an otherwise successful containment and redirection, consideration should be given to relaxing the criteria that was violated. As part of the evaluation of such an event, the testing laboratory should provide clear and indisputable evidence that barrier contact with the external vehicle guidance component led to the undesirable outcome.



Figure 5-1. Exit Box for Longitudinal Barriers

5.3 GEOMETRIC FEATURES

Tests of a geometric feature, such as a ditch, driveway, embankment, or curb, typically involve three-dimensional vehicular motions. Also, the duration of the test is usually long (up to 5 s or more) in comparison to a test of a barrier or other highway safety feature (typically 0.30 s or less). As a consequence, an unrestrained occupant can be expected to flail about the occupant compartment in three dimensions over extended time duration, possibly contacting a given surface(s) more than once. For these reasons, the OIV and RA values are generally not applicable. Fortunately, in tests of most geometric features, there are no design elements that would cause sudden and large vehicular velocity changes. The primary concern is overturn of the vehicle as it traverses the feature.

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

(a) Criterion F of Table 5-1B must be satisfied.

(b) Compute average accelerations in the longitudinal and lateral directions for each consecutive 50-ms period for the duration of the event.

(c) If the average longitudinal or lateral acceleration computed in Step b exceeds 2 G during any 50-ms period, calculate the OIV and RA values at the beginning of the period over which the average acceleration was computed, and evaluate the results according to Criteria H and I of Table 5-1B.