Summary of NCHRP Report 350

Periodic changes in crash testing and evaluation methodologies are necessary to keep pace with the changing vehicle fleet and operating conditions, and to address issues and data gleaned from ran-off-road crash data and to incorporate technological advances.

Guidelines for testing roadside appurtenances originated in 1962 with a one-page document – *Highway Research Circular 482* entitled "Proposed Full-Scale Testing Procedures for Guardrails." This document included four specifications on test article installation, one test vehicle, six test conditions and three evaluation criteria. In 1974, National Cooperative Highway Research Program (NCHRP) *Report 153*, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances" was published. This 16-page document provided the first complete test matrix for evaluating safety features. Data collection methods, evaluation criteria, and limited guidance on reporting formats were included. These procedures gained wide acceptance following their publication, but it was recognized at that time that periodic updating would be needed.

Published in 1978, Transportation Research Circular 191, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances" provided limited interim changes to *NCHRP Report 153* to address minor changes requiring modified treatment of particular problem areas. An extensive revision and update to these procedures was made in 1981 with the publication of *NCHRP Report 230*, "Recommended Procedures for the Safety Performance Evaluation of Highway Features." This 42-page document contained different service levels for evaluating longitudinal barriers whose test matrices included vehicles ranging from small passenger cars to intercity buses.

In 1993, *NCHRP Report 350*, "Recommended Procedures for the Safety Performance Evaluation of Highway Features" was published. This 132-page document represented a comprehensive update to crash test and evaluation procedures. It was developed by a TTI-led research team chosen in a competitive process by an expert panel under NCHRP Project 22-7. *NCHRP Report 350* incorporated significant changes and additions to procedures for safety-performance evaluation, and updates reflecting the changing character of the highway network and the vehicles using it. Changes included the introduction of multiple test levels, inclusion of matrices for other roadside features that had not previously been addressed, adoption of a new design test vehicle, more and different test conditions, etc.

NCHRP Report 350 was a consensus document of the roadside safety community. The recommended guidelines contained in *NCHRP Report 350* reflect input received from a large number of researchers, hardware manufacturers, user agencies at all levels, and other professionals in the field of roadside safety design. The report provides a basis on which the impact performance of roadside safety features can be uniformly assessed and compared. The

crash testing guidelines present matrices for vehicular tests that are defined in terms of vehicle type, impact conditions (i.e., speed and angle), and impact location. Information is provided regarding test article installation, test vehicle specifications, tolerances on impact conditions, and critical impact locations. *NCHRP Report 350* further prescribes data collection and analysis procedures, test evaluation criteria, and test documentation recommendations. The performance of a safety feature is evaluated in terms of occupant risk, structural adequacy, potential exposure of workers and pedestrians that may be in the debris path resulting from the impact, and post-impact trajectory and behavior of the vehicle.

The underlying philosophy of those behind the development of *NCHRP Report 350* was testing under "worst practical conditions." When selecting test parameters such as test vehicle type and weight, impact speed and angle, and point of impact, effort was made to specify the worst practical case conditions. Consideration was given to factors such as available crash data, current technology, vehicle sales, etc.

Some of the notable differences between *NCHRP Report 350* and its predecessor *NCHRP Report 230*, as excerpted from *Report 350*, were as follows:

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

- It uses a 4,409-lb, 3/4-ton pickup truck as the standard design test vehicle in place of the 4,500-lb passenger sedan to represent the growing population of light trucks in the vehicle fleet.

- It defines other test vehicles such as an 18,000-lb single-unit cargo truck and 80,000-lb tractor-trailer vehicles to provide the basis for optional testing to meet higher performance levels.

- It includes a broader range of tests for each category of safety feature to provide a uniform basis for establishing warrants for the application of roadside safety hardware that consider the levels of use of the roadway facility. Six basic test levels are defined for the various classes of roadside safety features.

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

The Federal Highway Administration (FHWA) formally adopted the new performance evaluation guidelines for highway safety features set forth in *NCHRP Report 350* as a "Guide or Reference" document in the Federal Register, Volume 58, Number 135, dated July 16, 1993, which added paragraph (a)(13) to 23 CFR 625.5. FHWA subsequently mandated that, starting in September 1998, only highway safety appurtenances that have successfully met the performance evaluation guidelines set forth in *NCHRP Report 350* may be used on new construction projects on the National Highway System (NHS).

CRASH TEST MATRIX

According to *NCHRP Report 350*, up to seven tests are recommended to evaluate gating W-beam guardrail terminals to test level three (TL-3). TL-3 is the basic test level for passenger vehicles to which most crash-tested safety devices in use on U.S. highways have been qualified. Of the seven terminal tests, four of them involve impacting the end of the terminal. These four tests are described below.

- **Test designation 3-30**: An 820 kg (~ 1,808 lbs.) passenger car impacting the terminal end-on at a nominal impact speed and angle of 62 mi/h and 0 degree, respectively, with the quarter point of the vehicle aligned with the centerline of the nose of the terminal.

- **Test designation 3-31**: A 2000 kg (~ 4,409 lbs.) pickup truck impacting the terminal end-on at a nominal impact speed and angle of 62 mi/h and 0 degree, respectively, with the centerline of the vehicle aligned with the centerline of the nose of the terminal.

- **Test designation 3-32**: An 820 kg (~ 1,808 lbs.) passenger car impacting the terminal end on at a nominal impact speed and angle of 62 mi/h and 15 degrees, respectively, with the centerline of the vehicle aligned with the centerline of the nose of the terminal.

- **Test designation 3-33**: A 2000 kg (~ 4,409 lbs.) pickup truck impacting the terminal end-on at a nominal impact speed and angle of 62 mi/h and 15 degrees, respectively, with the centerline of the vehicle aligned with the centerline of the nose of the terminal.

The crash test plan for the ET-Plus that was requested by FHWA involves running these four tests on ET-Plus systems installed at heights of both 27 ¾ inches and 31 inches.

EVALUATION CRITERIA

Crash tests performed under the guidelines of *NCHRP Report 350* are evaluated in accordance with evaluation criteria presented in Table 5.1 of that document. These criteria are based on three evaluation factors: structural adequacy, occupant risk, and post-impact vehicle trajectory. A summary of these evaluation factors and criteria is provided below.

Structural Adequacy – Depending on the type of safety device and its design function, the device should be able to contain and redirect the impacting vehicle, permit controlled penetration of the impacting vehicle, or bring the vehicle to a controlled stop in a predictable manner. In regard to end-on terminal tests, acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.

Occupant Risk – In general, occupant risk relates to the degree of hazard or risk of injury to occupants in the impacting vehicle. Occupant risk is assessed in terms of the relative velocity at

which a hypothetical, unrestrained occupant impacts an interior surface of the vehicle, and the subsequent occupant ridedown accelerations. These occupant risk indices are computed from the acceleration-time histories measured inside the impacting vehicle. Another element of the occupant risk evaluation is the risk of injury to occupants of the impacting vehicle, other traffic, pedestrians, or work zone personnel due to detached elements, fragments, or other debris form the test device. Penetration of the occupant compartment is not permitted.

Vehicle stability is another aspect of the occupant risk evaluation. For all tests involving passenger vehicles, a requirement for the safety of vehicle occupants is for the impacting vehicle to remain upright (i.e., no roll over) during and after the collision.

Post-Impact Vehicular Trajectory – The intent of this criteria is to assess the probability of a secondary collision of the impacting vehicle with other surrounding traffic based on the impacting vehicle's path and final resting position, thereby subjecting occupants in both the impacting vehicle and other vehicles to further risk of injury. It is preferable that the impacting vehicle's trajectory not intrude into adjacent traffic lanes. For gating terminal systems, vehicle trajectory behind the test article is acceptable.

The specific evaluation criteria from *NCHRP Report 350* relevant to end-on impacts with guardrail end terminal systems are provided in Attachment A.

ATTACHMENT A

NCHRP Report 350 Evaluation Criteria
(Relevant to Terminal Tests 30, 31, 32, and 33)

Structural Adequacy

C. *Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle.*

Occupant Risk

D. *Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.*

F. *The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.*

H. *Occupant impact velocities should satisfy the following:*

Longitudinal and Lateral Occupant Impact Velocity

Preferred	*Maximum*
9m/s	*12 m/s*

I. *Occupant ridedown accelerations should satisfy the following:*

Longitudinal and Lateral Occupant Ridedown Accelerations

Preferred	*Maximum*
15.0 Gs	*20 Gs*

Vehicle Trajectory

K. *After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.*

N. *Vehicle trajectory behind the test article is acceptable.*