AN OVERVIEW OF *NCHRP REPORT 350*

Hayes E. Ross, Jr.
Texas A&M University

I will be discussing National Cooperative Highway Research Program (NCHRP) Project 22-7, in which an update to *NCHRP Report 230* was developed. The project was indeed a team effort. Input was provided by a large number of people in various disciplines, not only nationally but internationally. The document, which will be published as *NCHRP Report 350*, is a consensus document and I am indebted to all those who provided comments and reviewed the drafts, especially the NCHRP advisory panel, chaired by Roger Stoughton of the California Department of Transportation, and Kenneth Opiela, NCHRP Senior Project Specialist.

This presentation will include a general overview of the document and how it differs from *Report 230*. It will also include a brief discussion of the potential impact *Report 350* will have on current practices, policies, and international harmonization.

The project began in June of 1989 and was completed in August, 1992. It was conducted at the Texas Transportation Institute, and Jarvis Michie with Dynatech Engineering Incorporated was a consultant/subcontractor on the project. We were fortunate to have Jarvis on the research team since he had written *Report 230*, and guidelines that preceded *Report 230*.

CHANGES INCORPORATED IN *REPORT 350*

Report 350 incorporated several major changes. The first one concerned the adoption of the International System of units (SI). To the extent possible a "hard conversion" procedure was used, in which English units are converted to the equivalent SI unit and then rounded. By so doing, it increased the requirements of some tests and it diminished the requirements of others, but in all cases the changes were not major. For example, a 60 mph test speed, which has been a standard value for high speed tests, converts to 96.6 km/h. The decision was made to round to 100 km/h, which is 62.1 mph.

The critical test speed for many breakaway features is at the lower end of the spectrum rather than the high end. The test speed on the low end has been 20 mph. In *Report 350* the speed was set at 35 km/h, or 21.7 mph. It was initially decided to round to 30 km/h, which is 18.6 mph. However, it was brought to our attention by those who design and use breakaway hardware that such a conversion would create an unnecessarily conservative test requirement since the 20 mph requirements of *Report 230* were believed to be very conservative. Not only are these features required to breakaway at low speeds, they are also required to do this for vehicles at the low end of the weight spectrum. Furthermore, the acceptable vehicular velocity change (and hence occupant risk measures) for breakaway features is much lower than for other features such as crash cushions, end treatments, etc.

Other major changes which will be discussed subsequently include test vehicles, more specific features, the contents and number of the test matrices, modifications to the evaluation criteria, and guidelines on selection of the impact point for redirection-type tests.

Also to be noted is that *Report 350* contains *guidelines*, as opposed to absolute standards, for testing and evaluating safety features. Adoption of the guidelines, in whole or in part, as a standard is at the discretion of federal and state transportation agencies. It is also to be noted that *Report 350* contains no selection criteria, or warrants, for features addressed therein. Features tested and evaluated according to the guidelines will have specific applications, but identification of these applications remains to be determined by the user agency or perhaps by the American Association of State Highway and Transportation Officials (AASHTO) or the Federal Highway Administration (FHWA).

TEST VEHICLES

The "basic" test vehicles, which are passenger vehicles, are the 820C and the 2000P. The 820C is a small car with a mass of 820 kg, essentially the same small car test vehicle used in *Report 230*. A major change was made in the adoption of the 2000P, which is a "3/4-ton" pickup truck with a curb weight or mass of approximately 2,000 kg, or 4,400 lb. The primary reason for selecting the 2000P vehicle was that it is believed to be a reasonable representative of the light-truck population. Light trucks, which include pickups, vans, and sport/utility vehicles, now make up a significant portion of the total passenger vehicle population in the USA, and indications

TABLE 1 COMPARISON OF 4500S AND 2000P VEHICLES

Parameter	Typical Values	
	4500S	2000P
Mass (kg)	2,040	2,000
Center of Mass		
Height (cm)	60	70
Fore-aft mass distribution (%)	55/45	58/42
Dimensions		
Wheelbase (cm)	305	335
Front overhang (cm)	110	80
Bumper height (cm)	45	55
Tire radius (cm)	38	41
Tire width (cm)	155	165

are that sales and use of light trucks will continue to increase for the foreseeable future. It was also selected since its mass approximated that of the 4,500 lb car so widely used in the past.

Other vehicles also can be used in the design and evaluation of a feature. The 700C test vehicle is a very small car with a mass of approximately 700 kg, or about 1,500 lb. Use of this vehicle is optional. If a developer or manufacturer of a safety feature feels confident the feature can meet test requirements using the 700C vehicle the option is available. Tests with the 820C vehicle are not necessary if tests with the 700C are acceptable. A manufacturer may have an advantage over the competition if his feature is the only one that satisfies test requirements with the 700C vehicle.

The 8000S vehicle is a 8,000 kg (about 17,600 lb) single unit truck. This vehicle has been used in recent years in the USA for the development and evaluation of bridge railings, in accordance with the AASHTO guide specifications published in 1989. Then there are two very heavy vehicles: the 36000V or 36,000 kg (about 79,300 lb) tractor van trailer, and the 36000T or 36,000 kg tractor tanker-type trailer vehicle that can be used in the testing. These vehicles are to be used in the development of high performance, or high containment, barriers.

Table 1 provides comparisons of the 2000P pickup truck with the 4,500 lb car previously used. It is only about 100 lb, or 45 kg, lighter than the 4,500 pound car. So there is not a lot of difference in the mass but there are differences in some of the other properties. Center of mass height of the 2000P vehicle is about 70 cm whereas the 4,500 lb car had a height of about 60 cm. With regard to the fore-aft mass distribution, the 4,500 lb car typically has about 55 percent on the front axle and 45 percent on the rear axle, whereas the pickup truck typically has about 58 percent on the front and 42 percent on the rear. The wheel base of the car is about 305 cm whereas the wheel base of the pickup is somewhat longer. The front overhang is shorter on the pickup truck 80 cm for the pickup versus 110 cm for the car.

With regard to the effect these changes will have on performance, a higher center of mass probably means the 2000P vehicle will be less stable and more prone to overturn. The shorter front overhang of the 2000P vehicle means the tire nearest the impact point will tend to impact a redirective feature, such as a guardrail, sooner than would have occurred on the 4,500 lb car. Further, the tire/wheel radius of the 2000P vehicle is larger. These changes may result in a greater tendency for the 2000P vehicle to climb up and over the face of the feature. Bumper height is another parameter of concern. The bumper height of the 2000P vehicle will typically be about 55 cm whereas the car was about 45 cm. All other factors being the same, performance is expected to degrade for many features as the bumper height increases.

Other factors that will potentially influence performance include crush stiffness and body design of the 2000P vehicle. It has a stiffer front end and it has two distinct body shells. For energy absorbing devices such as a crash cushion, the pickup will not absorb as much energy as the 4500 lb car did. Thus, an energy absorbing device whose performance is near recommended limits may not pass the pickup truck test. Tests have shown that the body design of the 2000P vehicle tends to reduce the impact loads slightly on a redirective feature.

TESTING AND EVALUATION

There are up to six test levels in *Report 350*, depending on the feature being evaluated. All six test levels apply to longitudinal barriers, test levels 2 and 3 apply to breakaway features, and test levels 1, 2, and 3 apply to crash cushions and end treatments.

Although selection guidelines or warrants do not presently exist, it is assumed that devices developed for test level 1 would be used for very low service level conditions such as in a work zone in an urban area where speeds are on the order of 50 km/h or less. Test levels 2 and 3 are the more basic test levels and the devices developed would have application on high speed facilities. Of these, level three is considered to be the basic level, but perhaps level 2 will also be widely used. Levels 4, 5, and 6 are for special, higher service level longitudinal barrier requirements.

Test and evaluation criteria are given in *Report 350* for the following features:

- Longitudinal barriers;
- Terminals and crash cushions;
- Support structures, traffic control devices, and breakaway utility poles;
- Truck mounted attenuators; and
- Geometric features.

Longitudinal barriers include roadside barriers, median barriers, and bridge railings; these types of barriers are referred to as safety barriers in Europe. There are three distinct parts of a longitudinal barrier of concern: the length-of-need section, the transition region in which the barrier may be connected to a longitudinal barrier of different lateral stiffness, and the end of the barrier. The first two are addressed within the longitudinal barrier test series, and the latter is addressed within the terminal and crash cushion series. Longitudinal barriers can be developed to any test level.

The next category includes longitudinal barrier terminals and crash cushions. The first three test levels apply to this category. That category is further subdivided into (a) terminals and redirective crash cushions and (b) non-redirective crash cushions. There was considerable discussion among members of the advisory panel and others from whom we sought advice as to required test conditions for crash cushions and terminals. Some felt that the tests should be selected so as to require all crash cushions to have redirective capabilities. However the consensus was that the updated test procedures for crash cushions should not be selected so as to eliminate future use of non-redirective systems. As a general rule the non-redirective sand-tub crash cushion has proven to be a reliable, cost-effective system, and is widely used throughout the USA.

Also addressed are test and evaluation procedures for support structures, work-zone traffic control devices, and breakaway utility poles. Included under the support structure category are sign and luminaire supports, emergency call boxes, and mailbox supports. Included under the work-zone traffic control devices are plastic drums, barricades, cones, chevron panels and their supports, and delineator posts and lights that may be attached to drums or barricades. Features within these categories can be designed and evaluated to test level 2 or 3. It was concluded that it would not be cost effective to develop one of these features for test level 1. In other words, it is believed that a feature developed for level 2 or 3 would also be cost effective for test level 1 as well.

Specific test guidelines are presented for truck-mounted attenuators (TMA). Whereas a TMA can be developed to test levels 2 or 3, most of the current designs were developed for level 2 conditions.

Very general guidelines for testing geometric features such as side slopes or ditches or median cross-overs, are also presented. However, there are no specific test levels for features of this type.

Table 2 shows tests designed to evaluate the strength or containment capabilities of longitudinal barriers. The first three test levels are conducted with the 2000P vehicle, at impact speeds of 50 km/h, 70 km/h, and 100 km/h, and an impact angle of 25 degrees. The corresponding speeds in miles per hour are also shown. It is noted that requirements of level 3 do not vary significantly from the basic requirements of *Report 230*, in terms of impact speed and angle and vehicular mass. For levels 4, 5, and 6, test vehicles range from the 8000S up to the 36000T. All three tests are conducted at 80 km/h, which is about 50 mph, and at a 15 degree impact angle.

Some of the criteria used to evaluate a given test were changed. There are no major changes in the structural adequacy requirements of *Report 230*. With regard to occupant risk criteria, it was decided to retain the "Flail Space Model." In this model the occupant is represented by a lumped mass that is allowed to move within a specified space until it impacts a surface. At initial contact, the impact velocity normal to the surface is computed, and is referred to as the occupant impact velocity (OIV). Following impact the mass is assumed to remain in contact with the surface and to experience the "ridedown" acceleration (RA) of the vehicle. Recommended limits of OIV and RA are given in two categories, "preferred" and "maximum." For all features except support structures and work-zone traffic control

TABLE 2 STRENGTH TESTS FOR LONGITUDINAL BARRIERS

Test Level	Vehicle	Impact Conditions	
		Nominal Speed (km/h,mph)	Nominal Angle (deg)
1	2000P	50, 31	25
2	2000P	70, 43	25
3	2000P	100, 62	25
4	8000S	80, 50	15
5	36000V	80, 50	15
6	36000T	80, 50	15

devices, the preferred and maximum OIV are 9 m/s and 12 m/s, respectively. For all features the preferred and maximum RA are 15 g's and 20 g's, respectively. Similar limits were given in *Report 230*. In addition, the lateral and longitudinal components of the OIV have the same limits in *Report 350* whereas in *Report 230* the lateral limit was approximately 30 percent less than the longitudinal limit. Based on a review of the literature and on discussions with experts, it was concluded thatlimits in the lateral and longitudinal directions should be equal. The OIV limits for support structures and work-zone traffic control devices are essentially the same as those in *Report 230*, 3 m/s preferred and 5 m/s maximum.

Some changes were made with regard to the post-impact trajectory criteria. The 15 mph (24.2 km/h) vehicular velocity change limit for redirective features was increased to 12 m/s (26.8 mph or 43.2 km/h).

Report 350 contains guidelines for identifying the critical impact point for a redirective feature. That is the point along the feature judged to have the greatest potential for causing snagging or pocketing of the vehicle with the barrier, or for causing structural failure of the feature.

THE POTENTIAL IMPACTS OF *REPORT 350*

Key issues related to *Report 350* include its adoption by FHWA, potential changes to current designs as a result of its use, selection guidelines or warrants for features developed according to *Report 350*, certification of testing agencies, and harmonization with European test standards. I will briefly discuss each of these issues.

Report 350 was officially adopted by FHWA through the Code of Federal Regulations to determine acceptability of safety features for use on the National Highway System. The effective date is August 16, 1993 for all new designs developed subsequent to that date. There is a nine-month transition period beginning August 16, 1993 for designs under development prior to that date. Also, there is a five-year grace period beginning August 16, 1994 for existing designs satisfying *Report 230* guidelines.

Based on limited testing to date, no changes are anticipated for concrete safety shaped barriers, sand-tub crash cushions, and breakaway support structures. There are indications that standard, 27-inch high W-beam barriers may have difficulty containing the 2000P vehicle at test level 3. There are also questions relative to the performance of some end treatments, crash cushions, and truck-mounted attenuators for impacts with the 2000P vehicle. It is also anticipated that multi-service level designs will be developed above and below the basic test level (level 3).

There are only minimal objective guidelines that can be used to determine where multi-service level features should be used. As previously discussed, *Report 350* permits design and evaluation of safety features for up to six test levels. Thus, there is a need for guidelines to identify conditions for which multi-service level features are warranted. TRB and AASHTO have identified development of such guidelines as a high priority research need. In a 1993 summer workshop, TRB Committee A2A04 strongly endorsed the need to develop use guidelines.

Another issue raised as a result of the publication of *Report 350* and the interest in international harmonization, is the certification of testing facilities. FHWA is considering the development of an electronic "black box" with accompanying software to establish the ability of an agency to accurately record and reduce crash test data. TRB committee A2A04 rated the need for certification as a high priority item.

Three items are related to the harmonization of USA guidelines and European standards for the impact performance of safety features. First, as previously discussed, *Report 350* is written with SI units. Furthermore, it is recommended that testing agencies calculate and report occupant risk parameters adopted

by the European Community (CEN). Finally, also as noted, the small car used in USA and CEN tests has similar characteristics, and test requirements for crash cushions and terminals are expected to be similar.

It has been a pleasure to have had the opportunity to work with many highway safety professionals, both nationally and internationally, in the preparation of *Report 350*. It is expected that the document will foster uniform test and evaluation procedures for highway safety features throughout the USA and other countries. More importantly, it is expected that use of the document will result in the design and implementation of improved safety features, thereby reducing the severity of accidents.