draft of the report that was produced in late 1990. The panel again took a very close look at all aspects of the proposed update to the procedures for safety performance evaluation in the context of the many new features and concepts that had emerged both in the United States and abroad.

After a thorough review of the first draft, the panel convened for a second time with the research team to go over each issue and establish a consensus to set the foundation for a second draft report. The second draft report was issued in the early 1991. It was initially reviewed by the project panel to ascertain that an effective set of safety performance evaluation procedures was evolving. The second draft report was then sent out for further review by about 100 additional individuals, including about 30 foreign representatives.

The comments of these reviewers were compiled in their entirety and transmitted to the research team. The set of returned comments, when typed single-spaced, were 75 pages long and represented more text than there was in the second draft of the report. Dr. Ross and Mr. Michie waded through all the comments and responded to all the major criticisms that were made. They then recommended a series of revisions to the procedures and met with the panel to weigh the validity of and the need for these revisions.

In early 1992 the third draft of the report was produced. After another panel review, final revisions were made, technical editing was completed, and the revised document — NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* — became available from TRB in March 1993. It was a long and arduous process that involved a lot of individuals. There were a lot of comments reviewed and pros and cons debated, and the various perspectives — manufacturers', state DOTs', and federal agencies' — were considered in the process of producing this consensus document.

Dr. Ross and Mr. Michie worked hard with the project panel to produce a viable set safety evaluation procedures that cover a broad range of roadside features and provide a basis for tailoring performance to roadway and traffic conditions. The project panel that served on a voluntary basis reviewed all materials, met on numerous occasions, and hammered out an updated set of procedures for the United States. The panel, under the guidance of Chairman Roger Stoughton, included Mr. James Bryden, Dr. Charles Dougan, Mr. Dennis Hanson, Mr. James Hatton, Mr. Walter Jestings, Mr. James Roberts, Mr. Florio Taminini, Mr. Tom Turbell, Mr. Harry Taylor, and the late Dr. Edward Post. In addition, Mr. Marty Hargrave and Mr. Leonard Meczkowski from the Federal Highway Administration were very instrumental in the review of the document.

UPDATE TO NCHRP REPORT 230

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National Cooperative Highway Research Program (NCHRP) Project 22-7 developed an update to NCHRP Report 230. The project was a team effort. Input was provided by a large number of people in various disciplines, not only nationally but internationally. The document, published as NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features,* is a consensus document. The NCHRP advisory panel, chaired by Roger Stoughton of the California Department of Transportation, and staffed by Kenneth Opiela, NCHRP senior project officer, provided comments and reviewed the drafts.

The project, which began in June 1989 and was completed in August 1992, was conducted at the Texas Transportation Institute. Jarvis Michie of Dynatech Engineering Inc. was a consultant/subcontractor on the project. Jarvis was a key member of the research team because he wrote Report 230 and guidelines that preceded Report 230.

One major change incorporated in Report 350 includes 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, those who design and use breakaway hardware stated 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 break away at low speeds, they also are 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, and so on.

Other major changes 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. In addition, 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.

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).

The basic test vehicles, which are passenger-type vehicles, include the 820C, a small car with a mass of 820 kg, which is 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 2000 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 United States, and indications 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.

Supplementary vehicles that can be used in the design and evaluation of a feature include the 700C test vehicle, which 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 is confident that 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 its feature is the only one that satisfies test requirements with the 700C vehicle.

The 8000S vehicle is a 8000-kg (about 17,600-lb) single unit truck. This vehicle has been used in recent years in the United States 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, a tractor van trailer with a mass of 36,000-kg (about 79,300 lb), and the 36000T, a tractor tanker-type trailer vehicle with a mass of 36,000 kg that can be used in the testing. These vehicles are to be used in the development of high performance, or high containment, barriers.

The 2000P pickup truck is only about 100 lb, or 40 kg, lighter than the 4,500-lb 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's 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 4,500-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.

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 50 km/h or less. Test levels 2 and 3 are the more basic test levels, and devices developed, therefore, would have application on high-speed facilities. Of these, level 3 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.

The features for which test and evaluation criteria are given in Report 350 include longitudinal barriers (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.

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*) nonredirective crash cushions. There was considerable discussion among the advisory panel and others about required test conditions for crash cushions and terminals. Some believed 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 nonredirective systems. As a general rule the nonredirective sand-tub crash cushion has proven to be a reliable, cost-effective system and is widely used throughout the United States.

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 levels 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 levels 2 or 3 would also be cost-effective for test level 1.

Specific test guidelines for truck-mounted attenuators (TMAs) can be developed to test levels 2 or 3; however, most of the current designs were developed for level 2 conditions.

There are very general guidelines for testing geometric features such as side slopes, ditches, and median crossovers; however, there are no specific test levels for features of this type.

Specific tests are 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. 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.

There are key changes in criteria used to evaluate a given test. 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 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 and 20 g, 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 that limits 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 (43.2 km/h).

Finally, 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.

It is expected that Report 350 will foster uniform test and evaluation procedures for highway safety features throughout the United States and other countries. More important, 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.