C. Rationale for Existing U.S. National Barrier Testing Procedures

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The large number of people who have chosen to spend their Sunday morning at this workshop attests to the importance of this topic as seen by us in the United States and those of you in the European Community, and other parts of the world. I wish you success in your efforts.

I would like to review with you a portion of the U.S. procedures for testing and evaluation of roadside hardware. Most of you are aware that there are two bases for the barrier test and evaluation criteria in the United States. One is centered on this document, the NCHRP Report 230, *Recommended Procedures for Safety Performance Evaluation of Highway Appurtenances*. I would like to talk to you about my perceptions about the background of this document—what it contains, and what people were thinking about. The other source of testing and evaluation criteria here in the United States, at the national level, is the standards and guidelines policies of the American Association of State Highway and Transportation Officials (AASHTO). Jim Hatton, who has been secretary to those efforts, will follow me and speak to that.

Purpose

Let's start off by asking the question, "What does this document say of itself? What is its purpose?" If you look at the Introduction and Commentary, it's pretty simple. The purpose is to compare the safety performance of two or more designs. We are concerned about absolute measures of safety evaluation, but the purpose is comparison—we need to keep that in mind.

Approach

The approach that was chosen in this document is that of the "practical worst case." By this, it means severe impact conditions are used, not typical ones. In other words, we cannot use the results of these tests to say "on the average, 'X' percent of injuries would be expected in the real world with this device under these conditions." It is not intended for such purposes. Roadside barriers and safety devices, etc., tend to "fall apart," i.e, show major performance differences at the practical extremes. That is where, for the purpose of crash tests, we tend to look, and that is the focus of this document.

Other occurrences in the real world were recognized but simply were felt to be too complex for this purpose and for this kind of document. For example, traffic rails are curved in the real world, but the criteria calls for testing straight rails. Typically, we're dealing with uneven roadsides, but we test on flat grades. Further, to the degree that soils are important, idealized soils are specified. These are the approaches that this document takes.

The document includes a cautioning note about the use of these procedures: "Specific questions concerning a device or specific site conditions may require crash tests 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." In other words, in the view of the writers of this document, neither it nor any other document can cover all the conditions that can exist in the real world. A professional engineer is going to have to think about specific sites and specific problems that may be peculiar to his country, state, or specific application.

Method

This report was developed in an iterative fashion in 1981; it is deliberative in its approach; and it is a consensus document. It is iterative in the sense that the first document that preceded it was prepared by a committee of the (then) Highway Research Board in 1962 as a one-page circular, Number 482, suggesting common ways to test guardrails so that people could compare the safety performance of these devices.

Nothing has changed since that time—that is still the purpose of this document. In 1974, under a contract with Southwest Research Institute, NCHRP Report 153 was written, which practically is the predecessor of NCHRP Report 230. All of the elements of NCHRP Report 230 are in Report 153: longitudinal barriers, impact attenuators, poles, signs, and luminaires. Transportation Research Circular 191, written in 1978, was an interim update of this document written by a task force of TRB Committee A2A04. Finally, in 1981, NCHRP Report 230, which is currently operative, was written.

So NCHRP Report 230 is iterative. It builds on earlier work; it did not start from "whole cloth" to develop these complex procedures.

It is a deliberative document. Even after these preceding rounds, comments from 50 individuals or agencies were received, and analyzed. The contractor prepared written responses to all comments received, which were reviewed in turn by an appointed ad hoc committee. This committee discussed both the comments of the individual submitters and the responses of the contractors. Southwest Research Institute, was represented by Jarvis Michie and Maurice Bronstad. This process occurred through several draft cycles and resulted in a consensus document.

Test Components

The document describes vehicles, impact conditions, and performance evaluation measures for each test, and also gives test report guidelines. That is, we must describe the vehicles to be used, specific impact conditions, and test outcome; together with guidelines to assist other people in evaluating what the test agency has seen. Finally, we have to document everything, because the purpose is to compare. We must preserve the results, so people can look at them later and form their own judgments. Let us look at these test components one at a time.

Vehicles

NCHRP Report 230 suggests two things: a minimum matrix of automobile tests, and a supplementary matrix of heavy-vehicle tests. Three vehicles are in the minimum matrix of cars by weight: 4,500, 2,250, and 1,800 lb. The supplementary vehicles suggested are buses (three different types); and the heaviest vehicle is a tractor-trailer of 80,000 lb.

Let us look at the background that led to the selection of the cars. In the 1960s, at the time the first circular was written, basically, cars, for practical purposes, were one size in this country. They weighed around 4,000 lb, and 4,500 lb was on the upper side. So, the first documents were written for these cars, and this weight of vehicle has carried through to the publication of NCHRP Report 230.

In the early 1970s, when NCHRP Report 153 was written, we went through a period in this country in which a large number of foreign cars (particularly the VW Beetle) that weighed under 2,000 lb were imported. Also, the United States began to manufacture compact-sized automobiles: namely, the Pinto and the Vega. The 2,250-lb Vega became a critical vehicle in determining the overturn of shaped concrete barriers in ongoing work at that time, and this weight of car was adopted into the procedures in NCHRP Report 153 in 1974.

At the time of writing NCHRP Report 230, something new happened. We could see a definite change in the vehicle fleet in the future—we knew it was coming because, after the oil embargo of 1974, all of the manufacturers in this country had committed themselves to increasing the fuel economy of their fleets. Interestingly enough, in 1979 we had insight in how they were going to do this, because a study done by NHTSA of the plans of domestic automobile manufacturers revealed this information. This study predicted the shift in weights of domestic automobiles manufactured in 1978 and in 1986. We are reviewing the background of a document that considers a range of vehicle weights. (The reason we are dealing with a range of vehicles will be discussed later.) In 1978, the upper tail of this range, above 4,500 lb, contained only 5 percent of all cars. The lower tail of the range, below 2,250 lb, also contained about 5 percent of all cars. So, 2,250 to 4,500 lb encompassed 90 percent of the weights of the domestically produced vehicles.

However, the comparable projection for 1986 said that the 4,500-lb car would no longer be produced. The 95-percentile car in 1986 was predicted to weigh 3,300 lb. It also indicated that to get that same distribution at the lower tail end of the curve, we needed to look at cars that were as light as 1,800 lb.

This issue was a serious one for those of us deliberating NCHRP Report 230, because we knew from our work that a number of devices behaved poorly in general when vehicle weight decreased. It was thus a safety issue to consider the lower end of that curve. On the other hand, the central issue of comparison with crash tests that had gone on in the past seemed to require that the 4,500-lb vehicle be retained in this document. As the heavy (4,500-lb) cars are used for strength tests, lighter cars would produce less demanding tests at the same speed and angle. In other words, we lessen safety standards by going from a 4,500- to a 3,300-lb car. However, we would also lessen safety standards by ignoring the fact that we were expecting vehicles to be downsized.

In order to be practical about this situation, we had to have cars to test. There were cars that were sold in this country in the low-weight range. The 1976 Honda Civic was one. In fact, we had to ballast these cars to get them up to 1,800 lb. They also had other attributes that met what the American manufacturer said was going to happen to the fleet in 1986. Front-wheel drive was to come in, getting rid of the heavy transmission. So we began testing with this car, and we wrote a document around vehicles that were as light as 1,800 lb.

Impact Conditions

A practical worst-case speed of 60 mph was selected for all devices. We knew that poles can behave more poorly at low speeds, so 20 mph was set for poles. Practical angles of 0 to 25 degrees were selected. Impact points were selected depending on whether we were talking about impacting the end of the device or the side of the device. On the ends, there are even more choices. The crash can be centered or off-centered. This discussion is in the commentary of the document.

Speed, angle, and impact conditions are specified for three general types of devices: traffic rails, impact attenuators, and poles. I'm going to cover the first two only, because the last one in this document has been completely superseded by the work of AASHTO, as covered by Jim Hatton.

For traffic rails, the combination selected for this document was our old friend, the 4,500-lb, 60-mph, 25-degree test. This strength test was retained because way back in 1962 it was selected as the basis of comparison—the purpose of this document. The 2,250-lb test was included because at the time NCHRP Report 230 was written, we knew that we needed to consider the 1,800-lb vehicle, but no one had conducted any tests with it. Thus, the document had to say that desirably for performance and safety evaluation, traffic rails should meet desired performance with an 1,800-lb vehicle at 60 mph and 15 degrees. However, if that was found to be impractical, satisfactory results with this intermediate 2,250-lb vehicle would be acceptable.

Subsequent to NCHRP Report 230, practical experience told us that we did not see any differences between most hardware types when we test at 15 degrees with 1,800-lb cars at 60 mph. Thus, despite the language in the document, practical conditions led to testing 1,800-lb cars at impact angles of 20 degrees in order to see differences.

Let us look at terminals and impact attenuators. First, when we are talking about terminals, guardrails, median barriers, and impact attenuators, we must consider two different impact areas—on the end, and on the side. There are two things that we look for in tests in general: structural strength and safety performance. NCHRP Report 230 examines structural strength using the 4,500-lb car and safety performance with the light car.

What other factors were present in 1981? In 1981, when we wrote this document, most of the impact attenuator applications were at elevated exit ramps and gores. The focus of attention for impact attenuators was thus on impact conditions that were predominantly head-on. Three of the four selected impact attenuator crash tests are on the device ends. Two tests with the heavy vehicle were suggested (or ordered, if you will, depending on whether you are going to treat this document as a guideline or a specification, respectively), to look at end head-on impact performance—the structural performance of the rail. Only one end-on test is for the safety performance with the lighter vehicle.

Tests of the side impact attenuators are with the 4,500-lb vehicle test at 60 mph at 20 degrees, where typically we had tested for traffic rails at 25 degrees, as is recommended for terminals. Why? The reason is the document's art-of-the- possible approach. The document is intended to be practical. At that time, all impact attenuators except the sand-filled devices performed very marginally at 20 degrees. In other words, it was not then thought possible to obtain satisfactory performance at 25 degrees. The document states, that when and if we got to the point where such devices could meet performance criteria in tests at 25 degrees, then a 25-degree criteria should be used.

These are the main reasons for the differences in impact conditions between these devices. Things have changed since that time. We now have impact attenuators that are used in situations that are called "terminals," and vice versa. This has been the subject of discussion, and my perception of thinking at the time this document was written.

Performance Evaluation

I have already mentioned that the evaluation criteria were recommended in Report 230 in three parts: structural strength, occupant risk, and vehicle trajectories. Structural strength says, for example, that a traffic rail intended to keep vehicles on the roadway side of a facility, should do that—the test vehicle should not penetrate through or go over the rail. That is the philosophy of how a device is designed to perform. Thus, traffic rails should redirect. Impact attenuators should result in controlled stopping. Breakaway signs or yielding signs need to behave in that manner, and no fragments should be left beneath the devices. These are qualitative judgments.

For occupant risk, a key assumption was made, that "design" occupants are unbelted. This is not true in today's world, but that was the assumption that was made. A flail space model was developed as a simple two-dimensional model to estimate the impact change of velocity at the time when the occupant first contacts the interior of a vehicle. A value was developed from the ratio of a limit velocity divided by a factor of safety. This model for the first occupant interior contact has been the primary measure, in my view, for evaluating devices under NCHRP Report 230.

Concern as to what happens after this theoretical first contact between the occupant and the vehicle was discussed in some detail during NCHRP Report 230 deliberations. Thus, measures of the ridedown acceleration were proposed. This measure is expressed as a limit acceleration that occurs after the time that the occupant first contacts, divided by a factor of safety. This measure derived from the NHTSA Standard 208 Occupant Protection proposals at that time, which were direct measures of occupants.

The NCHRP Report 230 measurements are made on vehicles and used to infer occupant response. It was recognized that this is a poor-quality link from which to measure safety, but at the time, given the limits proposed, the results were not likely to govern or control in many cases. So the ridedown model is in the document, and has not proven to be much of a problem.

The longitudinal limit velocity of 40 ft/sec of the flail space model for vehicle-occupant contact was derived from the work of Patrick in the late 1950s. In impacts of cadavers against rigid surfaces, the velocity represented the threshold for skull fracture. For the lateral limit velocity change, researchers from Southwest Research Institute brought to our attention French research that, at the time, suggested that a limit lateral velocity of 30 ft/sec might be the threshold of serious injury—the so-called AIS-3 injuries.

The factors of safety are not intended to have a consistent likelihood of injury between different device types out in the real world, between impact attenuators and breakaway signs, but again are intended to be art-of-the-possible numbers. In other words, were there several devices, or concepts, judged to be practical and reasonable that could meet the criteria? So factors of safety differ for different types of devices.

Consider for example, longitudinal pole impacts. For sign and luminaire supports, a factor of safety of 2.67 is recommended. This produces, when you divide 40 ft/sec by 2.67, a recommended change in velocity when the occupant hits the interior compartment of 15 ft/sec. By contrast, it was thought that when and if we ever got to the point where we could develop breakaway utility poles, that owing to their larger mass, these criteria would be very difficult to meet. Thus for utility poles a factor of safety of 1.33, which produces a change in speed of 30 ft/sec, is specified. Again, art-of-the-possible philosophy.

For vehicle trajectory, again some qualitative and some quantitative judgments were made. Overturns are not allowed because we know overturns tend to be very harmful. For redirection impacts, the thought was (after much debate) to compare the results of previous crash tests that were judged otherwise successful, to select the limit of the change in speed during barrier contact in an attempt to limit the impact forces during collision with the traffic rail. The suggestion was to keep it less than 15 mph, and owing to the concern of rebound back into the traffic or across the roadway, to limit the exit angle to less than 60 percent of the impact angle. Those were the vehicle trajectory requirements.

Test Report

Finally, test information has to be documented in a way that people at a later time can make comparisons. If you look in the back of NCHRP Report 230, there is a very, very important page, the report page. It calls for a strip of photographs and measurements of the initial test conditions, and certain test outcomes. This enables people to make a decision quickly and at a glance as to whether or not they want to know more about that device or consider it for their application.

Summary

I have tried to lead you through my impressions of key background relating to the development of the NCHRP 230 crash testing procedures. It is important to realize that this document is dated 1981. Its purpose is to compare safety devices; its philosophy is practical worst-case testing conditions; and its approach is to use the art-of-the-possible.