ASSESSMENT OF NCHRP REPORT 350 TEST CONDITIONS

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ABSTRACT

This paper presents the results of an assessment on the appropriateness of test conditions specified in NCHRP Report 350. This work was conducted under NCHRP Project 22-14, "Improvement of the Procedures for the Safety Performance Evaluation of Roadside Features." The assessment was centered on the basic Test Level 3 (TL-3) and addressed these two areas of interest:

- Effects of higher speed limit on impact speed.
- Appropriateness of 25 degrees for the impact angle.

The following conclusions and recommendations are drawn based on results of the analysis,

- Maintain the current test impact speed of 100 km/h (62.2 mph).
- Maintain current impact angle of 25 degrees for test 11 of length-of-need sections of permanent longitudinal barriers.
- Reduce test impact angle from 25 to 20 degrees for test 11 of length-of-need sections of temporary longitudinal barriers.
- Reduce test impact angle from 25 to 20 degrees for test 21 of barrier transition sections.

However, it should be emphasized that the selection on impact conditions is more of a policy decision than a technical issue to be resolved in the update of NCHRP Report 350 guidelines.

INTRODUCTION

This paper presents the results of an assessment on the appropriateness of test conditions specified in National Cooperative Highway Research Program (NCHRP) Report 350.[1] This work was conducted under NCHRP Project 22-14, "Improvement of the Procedures for the Safety Performance Evaluation of Roadside Features."[2] The assessment was centered on the basic Test Level 3 (TL-3) since very little has been done at the other test levels and Test Level 3 is the basic level used for devices on the National Highway System (NHS). Specifically, the following two areas of interest are addressed:

- Effects of higher speed limit on impact speed. The impact speed for TL-3 test conditions was set at 100 km/h (62.2 mph) under NCHRP Report 350. Since the maximum speed limit at that time was 105 km/h (65 mph) on rural Interstate highways and 88.5 km/h (55 mph) on all other highways, a test speed of 100 km/h (62.2 mph) seemed appropriate. However, since the publication of the document, the national speed limit of 88.5 km/h (55 mph) was repealed and many states have adopted maximum speed limits of up to 121 km/h (75 mph). Questions have been raised regarding the appropriateness of using 100 km/h (62.2 mph) as the test speed given the higher speed limits and some have suggested that the impact speed be increased to 110 km/h (68.4 mph).

- Appropriateness of 25 degrees for the impact angle. An impact angle of 25 degrees is specified in NCHRP Report 350 for length-of-need and transition tests of longitudinal barriers to evaluate their strength and containment capabilities. However, in many tests with the 2000-kg (4,409 lb) pickup truck (2000P test vehicle), it was noted that failures were not related to the strength of the test article, but rather with the stability and severity measures of the test vehicle. Since it often causes an evaluation of stability instead of containment capacity, concerns have been raised regarding the appropriateness of the 25 degree impact angle and some have suggested that the impact angle should perhaps be reduced to 20 degrees. Note that the impact angle of 20 degrees is currently used for small car severity tests and pickup truck terminal tests at the beginning of length-of-need (LON).

ASSESSMENT OF TEST CONDITIONS

Table 1 summarizes the test designations and test conditions for the various roadside safety features specified in the NCHRP Report 350 guidelines under Test Level 3 (TL-3), including the test vehicle, the nominal impact speed and angle, and the impact point on the device. Also, an assessment on whether the test is affected by impact speed only (A) or by a combination of impact speed and angle (B) is provided in the table.

The nominal impact speed for all tests under TL-3 conditions in NCHRP Report 350 is 100 km/h (62.2 mph), except for the low-speed tests for support structures, work zone traffic control devices, and breakaway utility poles (tests 60, 70 and 80). Two tests have a nominal impact angle of 25 degrees, which are test 11 for the length-of-need and test 21 for the transition section of a longitudinal barrier. For terminals and redirective crash cushions, a lower nominal impact angle of 20 degrees is used for all redirectional (including reverse direction) impacts.

Effect of Higher Speed Limit on Impact Speed Distribution

A national speed limit of 88.5 km/h (55 mph) was imposed in 1974 in response to the oil embargo and shortage. This national speed limit was first relaxed in 1991, allowing the speed limit on rural interstate highways to increase to 105 km/h (65 mph), and was then totally repealed in 1995. Consequently, the states raised the speed limits on their highways in 1996. The majority of the states raised the maximum speed limits to 105 km/h (65 mph) or 113 km/h (70 mph), while a few states increased their speed limits to 120.7 km/h (75 mph). However, there is no uniformity among the states as to the maximum speed limit or the speed limits used on different highway types.

To properly assess the effects of the higher speed limit, it is necessary to relate the test conditions to the impact speed and angle distributions of real-world crashes. Unfortunately, the limited data available on real-world impact conditions[(3)] are over 15 years old and were collected at a time when the national speed limit was 88.5 km/h (55 mph). The available data on the distributions of the impact conditions was, therefore, analytically revised to reflect the higher speed limits.

Table 2 shows the revised distributions of impact speed and angle. It is estimated that 2.84 percent of crashes have impact speeds between 100 km/h (62.2 mph) and 110 km/h (68.4 mph) and another 7.3 percent have impact speeds above 110 km/h (68.4 mph). Also, it is estimated that 16.36 percent of the crashes have impact angles above 25 degrees and another 11.45 percent range between 21 and 25 degrees. Combining impact speed and angle, it is estimated that 1.65 percent of crashes have impact speed and angle above the nominal TL-3 test conditions of 100 km/h (62.2 mph) and 25 degrees and 2.82 percent of crashes exceed 100 km/h (62.2 mph) and 20 degrees.

Another parameter required to assess the effect of revising the test conditions is the resulting change in injury severity, i.e., number of fatalities and injuries per year. Unfortunately, the relationships between impact speed and injury severity are not well established for most roadside safety features. Thus, assessment regarding severity is based mostly on engineering judgement with very limited supporting data.

Effect of Higher Impact Speed on Performance of Roadside Safety Features

Increasing the impact speed from 100 km/h (62.2 mph) to 110 km/h (68.4 mph) would have significant effects on the majority of the tests specified under NCHRP Report 350. Brief discussions on the potential effects are presented in the following sections. Note that the effects of increased impact speed on longitudinal barrier length-of-need and transition designs are discussed in the next section under combined impact speed and angle test conditions.

<u>Crash cushions</u>. Increasing the impact speed would have profound effects on existing crash cushions, particularly with regard to their required capacity and length. The increase of 10 percent in impact speed is equivalent to a 21 percent increase in kinetic energy. Most existing TL-3 crash cushions have some reserve capacity to handle impacts slightly above 100 km/h (62.2 mph), but not enough to dissipate the kinetic energy at 110 km/h (68.4 mph). Thus, the existing crash cushions will have to be redesigned to accommodate the higher impact speed. Fortunately, many existing crash cushions are modular in nature and the energy-absorbing capacity of the crash cushion could be increased by adding one or more modules with minor modifications to the structure containing the modules. In fact, there are existing crash cushions that have been configured for impact speeds of up to 112.6 km/h (70 mph). However, tests of these configurations have typically been limited to head-on impacts with the 2000P test vehicle and their performance under other test conditions at high speed is unknown.

The effect of higher impact speed may be more critical for the small passenger car head-on impacts, both at zero (0) and 15 degrees (tests 30 and 32). A review of crash test results indicates that the performance of some of the existing crash cushions are marginal in terms of meeting occupant risk severity criteria, and even modest increases in impact speed could result in unacceptable occupant risk values and require design modifications to some crash cushions.

With the increase in impact speed, the capability of a redirective crash cushion to contain and redirect the 2000P test vehicle impacting at the beginning of length-of-need (test 35 or 37) and the ability of a non-redirective crash cushion to safely stop the 2000P test vehicle prior to impact with the corner of the hazardous object being shielded (test designation 44) would have to be assessed. It appears from crash test results that the performance of some of the existing crash cushions are somewhat marginal for this structural adequacy test and the increased impact speed could cause problems and require design modifications to some crash cushions.

Therefore, if the impact speed is increased crash cushions will have to be re-tested and evaluated. However, the crash test matrix could probably be reduced to three tests for this purpose for existing crash cushions. The first is the pickup truck head-on test (test 31 or 41) to assess the energy-absorbing capacity of the crash cushion and its ability to safely handle the higher impact speed. The second test is a small car end-on test to assess the severity associated with the higher impact speed. Depending on the design, the critical small car end-on test may be a head-on, offset test (test 30 or 40) or a 15-degree impact on the nose (test 32 or 42). The previous compliance testing conducted on the existing attenuator could be used to help identify which test is more critical. The third test is the pickup truck structural adequacy test (test 35, 37, or 44) to assess the ability of the crash cushion to contain and redirect the impacting vehicle or to protect the impacting vehicle from a “coffin corner” hit.

<u>Terminals</u>. The effects of increasing the impact speed are expected to have mixed consequences for terminals depending on the design and the energy dissipation mechanism. For gating terminals, the higher impact speed would have minimal effect for the pickup truck head-on impact (test 31) other than the perils of vehicle stability and trajectory associated with higher speed after gating though the terminal. For the small car head-on impacts (tests 30 and 32), the crash test results are more marginal and the higher impact speed could possibly have an adverse effect on the test outcome for some systems.

For extrusion type energy-absorbing terminals, the capacity to handle the higher impact speed should pose little problem. Field experience with some energy absorbing terminals has shown that they perform well in crashes with impact speeds well above 100 km/h (62.2 mph). The length of the terminal may have to be increased to accommodate the higher kinetic energy level: any design modification will likely be minor in nature, such as replacing standard line posts with breakaway CRT posts. However, the inertial impulse associated with accelerating the impact head may pose some problem for the small car head-on tests (tests 30 and 32) at the higher impact speed and some redesign to reduce the weight of the impact head may be necessary.

The higher impact speed could pose potential problems for terminal designs with staged or discrete energy absorption mechanisms. As with the crash cushion, the problem is related to the capacity of the energy absorber and its ability to dissipate the additional 21 percent of kinetic energy. For some terminals, the staged energy absorbers could be lengthened to accommodate the higher impact speed. For other terminals, other design constraints may prevent the use of a longer energy absorber and thus the ability to accommodate the higher impact speed. In addition, the higher impact speed itself could also pose a problem for small car head-on impacts (tests 30 and 32) due to the inertial effects, particularly if the device is lengthened..

The redirective capability of a terminal to contain and redirect the 2000P test vehicle impacting at the beginning of length-of-need (test designation 35) at the higher impact speed may also have mixed consequences. Crash test results indicate that some of the flared terminals (both gating and energy absorbing) are at or near their capacity in terms of their structural adequacy and it is questionable if these terminals could handle the increased impact speed without modification. For tangent terminals, there is a better chance for the systems to handle the higher impact speed in a satisfactory manner. It should be noted, however, that there are means to increase the redirective capability of a terminal, such as reducing the post spacing, if redesign becomes necessary.

If the impact speed is increased, the terminals will have to be re-tested and evaluated. However, as with the crash cushions, the crash test matrix for re-evaluating an existing system can probably be reduced to only three tests. The first is the pickup truck head-on test (test 31) to assess the energy-absorbing capacity of the terminal and its ability to safely handle the higher impact speed. The second test is the small car head-on test (test 30) to assess the severity associated with the higher impact speed. The third is the pickup truck structural adequacy test (test 35) to assess the ability of the terminal to contain and redirect the impacting vehicle.

Truck-mounted attenuators (TMAs). Increasing the impact speed would exceed the capacity of most, if not all, existing TMAs. Most existing TL-3 TMAs are near capacity to handle 100 km/h (62.2 mph) impacts and there is not enough reserve capacity to dissipate the additional kinetic energy at 110 km/h (68.4 mph). Unlike crash cushions, other design constraints, such as the overall length, turning radius, and weight of the TMA, may prevent the simple solution of lengthening the TMA. Thus, major design modifications would be needed to accommodate the higher impact speed and the redesigned TMAs would have to be retested to assess their impact performance.

Breakaway supports. For breakaway devices, two crash tests are required with the 820C test vehicle: a low-speed test (test 60) and a high-speed test (test 61). The high-speed test is intended to evaluate vehicle and test article trajectory and the increase in impact speed from 100 km/h (62.2 mph) to 110 km/h (68.4 mph) would likely have only minor effects on the test outcome. However, for systems that are very heavy or have a marginal breakaway mechanism that barely met the occupant risk criteria at the current 100 km/h (62.2 mph) impact speed, the higher impact speed could result in their failure.

Work zone traffic control devices. Increasing the impact speed would likely have little or no effect on the impact performance of work zone traffic control devices other than a slight increase to the potential problem with vehicle stability and trajectory associated with higher speeds.

Summary. The increase of the impact speed from 100 km/h (62.2 mph) to 110 km/h (68.4 mph) would have significant effects on many existing roadside safety devices. Some of the devices could be redesigned to accommodate the higher impact speed with minor modifications while others would require major modifications. Due to other design constraints, some devices may not be able to accommodate the higher impact speed regardless. Increasing the impact speed could result in a whole new generation of roadside safety hardware. In return, the higher impact speed would cover an additional 2.84 percent of real world crashes, increasing the percentage of crashes with impact speeds equal to or less than the design test speed from about 90 percent to 92.7 percent.

Since it is not possible to estimate the benefits in terms of reduction in severe to fatal injury crashes, it is difficult to assess if the improvement in the performance of the device tested to a higher impact speed justifies the expenses associated with a new generation of safety devices. It appears, in the authors' opinion, that maintaining the current test impact speed of 100 km/h (62.2 mph) is the most logical and prudent approach. However, this may be more of a policy decision than a technical issue to be resolved in the update of NCHRP Report 350 guidelines.

Appropriateness of 25-degree Impact Angle

As shown previously in Table 2, 16.36 percent of single-vehicle, ran-off-road crashes have impact angles of over 25 degrees. In other words, the impact angle of 25 degrees currently used in NCHRP Report 350 guidelines is equal to or greater than the impact angle for 83.64 percent of single-vehicle, ran-off-road crashes. If the impact angle is decreased to 20 degrees, another 11.45 percent of the crashes would exceed the design impact angle, reducing the total of real world crashes covered to only 72.2 percent.

However, in redirection impacts, impact angle must be viewed in conjunction with impact speed. When impact speed and angle are taken into consideration together, only 1.65 percent of impacts exceed the combined design impact condition of 100 km/h (62.2 mph) and 25 degrees. If the impact angle is reduced to 20 degrees and the impact speed remains unchanged at 100 km/h (62.2 mph), this percentage is increased to 2.82 percent. If the impact speed is increased to 110 km/h (68.4 mph) and the impact angle remains unchanged at 25 degrees, the percentage is reduced to 1.19 percent. On the other hand, if the impact speed is increased to 110 km/h (68.4 mph), but the impact angle is lowered to 20 degrees, the percentage increases slightly to 2.03 percent.

Also, it should be noted that the impact speed and angle distribution is for all single-vehicle, ran-off-road crashes and does not take into account lateral offset, which could become a factor for longitudinal barriers. The two tests with nominal impact angle of 25 degrees are test 11 for the length-of-need and test 21 for the transition section of a longitudinal barrier. Since locations of longitudinal barriers are typically just beyond the shoulder, or 3 to 4 m (10 to 13 ft) from the edge of the travelway, the maximum attainable angle is limited by the lateral offset.

The maximum attainable angle for a given speed and lateral offset can be investigated theoretically using a point-mass model and assuming maximum steering and a coefficient of friction of 0.7, which is typical of a dry pavement. In order to reach an impact angle of 25 degrees at a speed of 100 km/h (62.2 mph), the lateral offset has to be approximately 10.5 m (34.5 ft) under the tracking conditions assumed in the analysis. For the same speed of 100 km/h (62.2 mph), the lateral offset distance required to attain an impact angle of 20 degrees is 6.8 m (22.2 ft). Of course, as one would expect, the angle decreases as the speed increases. At a speed of 110 km/h (68.4 mph), the corresponding lateral offset to reach an impact angle of 25 degrees and 20 degrees are 12.7 m (41.8 ft) and 8.2 m (26.9 ft), respectively.

To put these lateral offsets into the perspective of a highway setting, consider the following three scenarios: the vehicle is in the first, second or third lane next to the shoulder. The assumptions are: lane width 3.7 m (12 ft), longitudinal barrier located 4 m (13 ft) from the edge of the travelway, maximum steering and 0.7 coefficient of friction. Note that these three scenarios are equivalent to lateral offsets of 5.1, 8.8 and 12.5 m (16.6, 28.7, and 40.8 ft). Table 3 summarizes the maximum attainable angles for various speeds under these three scenarios.

For a typical two-lane undivided highway or a four-lane divided highway, vehicles traveling at 100 km/h (62.2 mph) would not be able to attain an impact angle of 25 degrees departing from either lane (17.2 degrees for 1 lane and 22.8 degrees for 2 lanes). It would require a four-lane undivided highway or a 6-lane divided highway before an impact angle of 25 degrees can be reached at that speed (27.2 degrees for 3 lanes).

This is not to say that it is impossible to have a higher impact angle. One scenario is for a vehicle to first depart the travelway to one side, the driver over corrects and departs on the other side with a much higher angle than that originally attainable from the travel lane. However, this analysis does serve to illustrate that the proximity of longitudinal barriers to the edge of travelways would limit the attainable impact angle. For an impact speed of 100 km/h (62.2 mph), there is little question that an impact angle of 25 degrees is a rare event.

Another consideration is the point of impact. Both tests 11 and 21 specify the point of impact to be the critical impact point (CIP). In the case of test 11 for the barrier length-of-need, the CIP is typically selected to result in maximum potential for the vehicle to snag at a post with a rail splice. Note that the CIP region is a recurring event since there is a rail splice every 3.8 m (12.5 ft) or 7.6 m (25 ft), depending on the rail section length used. Also, past experience has shown that the CIP for a longitudinal barrier length-of-need is not very sensitive. For example, for a strong-post W-beam guardrail system, the CIP region could easily cover a 1-m (3.3-ft) area. Thus, the CIP region covers 1 m (3.3 ft) every 3.8 m (12.5 ft) or 7.6 m (25 ft), or approximately one-quarter or one-eighth of the guardrail, respectively.

In the case of test 21 for the barrier transition section, the CIP is typically selected to result in maximum potential for the vehicle to snag at the end of the bridge rail or the first bridge post. In this case, the CIP typically varies within a range of 0.3 to 0.6 m (1 to 2 ft) within 1.5 to 3 m (5 to 10 ft) of the end of the bridge. Note that there is only one CIP region for a given transition section, i.e., a non-recurring event. Thus, the probability of impacting the CIP region of the transition section of a longitudinal barrier is an extremely rare event.

To illustrate the rarity of such an impact, consider a highway with an average daily traffic (ADT) of 30,000. Assume that vehicle encroachments are random and uniform along the highway at an average rate of 0.0003 encroachment per km (0.00018 encroachment per mile) per year per vehicle per day (as used in the ROADSIDE program). The expected frequency for an errant vehicle to impact within the CIP region of a given transition section is less than (0.6/1000)*0.0003*30,000 = 0.0054 impact per year (or one impact every 185 years). The expected frequency for even impacting somewhere within the 3-m (10-ft) transition section is less than 0.027 per year (or one impact every 37 years).

It may, therefore, be argued that the specified test conditions of nominal impact speed and angle of 100 km/h (62.2 mph) and 25 degrees at the critical impact point is overly restrictive for the transition section. It may be reasonable to reduce the nominal test impact angle from 25 to 20 degrees.

The counter argument is that reducing the impact angle from 25 to 20 degrees would lower the structural capacity of the transition since the impact severity (IS), i.e., lateral component of the impact energy, would be reduced by 34.5 percent. However, this is not a real concern since the transition section is much stronger than the length-of-need section of the approach guardrail with larger and longer posts, closer post spacing, nested rail elements, etc. Since the guardrail length-of-need section has to meet the structural adequacy criteria, there is no reason to be concerned with the structural adequacy of the transition section.

As for test designation 11 for the barrier length-of-need section, an argument similar to that for the transition section would be less compelling. While longitudinal barriers are typically located just beyond the shoulder area, there are occasions, particularly for guardrails, where the barriers are placed with greater lateral offsets, such as around bridge piers or fixed objects. Also, as discussed previously, the probability of impacting within the CIP region is much higher for length-of-need sections than for transition sections since the CIP is a recurring event.

A much better argument can be made for reducing the impact angle from 25 to 20 degrees for the length-of-need structural adequacy test of temporary longitudinal barriers used in work zones. Due to restrictive conditions in work zones, the barriers are typically located very close to the edge of the travelway, much closer than that of a permanent installation. As discussed previously, the close proximity of the barrier to the travelway would limit the impact angle such that an impact angle of 25 degrees in combination with a 100 km/h (62.2 mph) impact speed is extremely unlikely. Thus, it appears that the impact angle of 25 degrees for temporary longitudinal barriers may be overly restrictive.

An argument for reducing the impact angle from 25 to 20 degrees can also be made for a higher impact speed of 110 km/h (68.4 mph). The percentage of crashes exceeding the test conditions would decrease from 1.65 to 1.19 percent if the impact angle remains unchanged at 25 degrees, and would only increase to 2.03 percent if the impact angle is lowered to 20 degrees. Further, with the higher speed, it is more difficult to attain an impact angle of 25 degrees. As shown in Table 3, even with 3 lanes of travel, a vehicle could not reach 25 degrees at a speed of 110 km/h (68.4 mph) if the assumed conditions are valid. Also, there are indications suggesting that the most commonly used W-beam guardrail systems would experience some difficulty in meeting test conditions of 110 km/h (68.4 mph) and 25 degrees, but have a reasonably good chance of meeting test conditions of 110 km/h (68.4 mph) and 20 degrees.

SUMMARY AND CONCLUSIONS

Based on results of the analysis, the conclusions and recommendations are summarized as follows:

- Maintain the current test impact speed of 100 km/h (62.2 mph). The increase of the impact speed from 100 km/h (62.2 mph) to 110 km/h (68.4 mph) would have very significant effects on many of the existing roadside safety devices. Some of the devices could be redesigned to accommodate the higher impact speed with minor modifications while others would require major modifications. Due to other design constraints, some devices may not be able to accommodate the higher impact speed regardless. Increasing the impact speed could result in a whole new generation of roadside safety hardware. In return, the higher impact speed would only cover an additional 2.84 percent of the crashes, increasing the percentage of crashes with impact speeds equal to or less than the design test speed from about 90 percent to 92.7 percent.

- Maintain current impact angle of 25 degrees for test 11 of length-of-need sections of permanent longitudinal barriers. There is no strong argument for reducing the impact angle from 25 to 20 degrees at this time. However, if a higher impact speed of 110 km/h (68.4 mph) is adopted, there is a reasonable argument for an associated reduction in impact angle. It is believed that the existing W-beam guardrail systems may have difficulty in meeting the higher impact speed unless the impact angle is reduced to 20 degrees.

- Reduce test impact angle from 25 to 20 degrees for test 11 of length-of-need sections of temporary longitudinal barriers. A strong argument can be made that the impact angle of 25 degrees for test 11 of length-of-need sections of temporary longitudinal barriers is overly restrictive due to the typical placement of temporary barriers at or near the edge of the travelway.

- Reduce test impact angle from 25 to 20 degrees for test 21 of barrier transition sections. A strong argument can be made that the impact angle of 25 degrees for test 21 for barrier transition sections is overly restrictive due to the extremely low probability of a vehicle impacting the transition within the critical impact point (CIP) region with an impact speed and angle above the design values.

However, it should be emphasized that the selection on impact conditions is more of a policy decision than a technical issue to be resolved in the update of NCHRP Report 350 guidelines.

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LIST OF TABLES

TABLE 1. Test Conditions -- NCHRP Report 350

Roadside Feature	Test Designation	Test Vehicle	Impact Speed (km/h)	Impact Angle (deg.)	Point of Impact	Comment*
Longitudinal Barrier Length of Need (LON)	10	820C	100	20	Critical Impact Point	B
	11	2000P	100	25	Critical Impact Point	B
Longitudinal Barrier Transition	20 (optional)	820C	100	20	Critical Impact Point	B
	21	2000P	100	25	Critical Impact Point	B
Terminals and Redirective Crash Cushion	30	820C	100	0	Nose of Device	A
	31	2000P	100	0	Nose of Device	A
	32	820C	100	15	Nose of Device	B
	33	2000P	100	15	Nose of Device	B
	34	820C	100	15	Critical Impact Point	B
	35	2000P	100	20	Beginning of LON	B
	36	820C	100	15	Beginning of LON	B
	37	2000P	100	20	Beginning of LON	B
	38	2000P	100	20	Critical Impact Point	B
	39	2000P	100	20	Reverse Direction (L/2)	B
Non-redirective Crash Cushion	40	820C	100	0	Nose of Device	A
	41	2000P	100	0	Nose of Device	A
	42	820C	100	15	Nose of Device	B
	43	2000P	100	15	Nose of Device	B
	44	2000P	100	20	L/2	B
Truck Mounted Attenuator (TMA)	50	820C	100	0	Nose of Device	A
	51	2000P	100	0	Nose of Device	A
	52 (Optional)	2000P	100	0	Nose of Device	A
	53 (Optional)	2000P	100	10	Nose of Device	B
Support Structure	60	820C	35	0-20	Not Specified	A
	61	820C	100	0-20	Not Specified	A
Work Zone Traffic Control Device	70	820C	35	0-20	Not Specified	A
	71	820C	100	0-20	Not Specified	A
Breakaway Utility Pole	80	820C	50	0-20	Not Specified	A
	81	820C	100	0-20	Not Specified	A

* A -- Impact speed only. B -- Combination of impact speed and angle.

TABLE 2. Revised Impact Speed and Angle Distributions

Impact Speed (km/h)	Impact Angle (Degrees)						Total
	<=5	6-10	11-15	16-20	21-25	>25	
<=50	0.0534	0.1253	0.1244	0.0945	0.0631	0.0901	0.5507
51-70	0.0187	0.0439	0.0435	0.0331	0.0221	0.0315	0.1928
71-100	0.0150	0.0353	0.0350	0.0266	0.0178	0.0254	0.1551
101-110	0.0028	0.0065	0.0064	0.0049	0.0033	0.0046	0.0284
>110	0.0071	0.0166	0.0165	0.0125	0.0084	0.0119	0.0730
Total	0.0969	0.2276	0.2258	0.1716	0.1145	0.1636	1.0000

TABLE 3. Maximum Attainable Angle by Speed and Offset

Speed, km/h (mph)	Maximum Attainable Angle (deg)		
	1 Lane	2 Lanes	3 Lanes
50 (31.1)	34.9	46.5	56.2
60 (37.2)	28.9	38.4	46.2
70 (43.5)	24.7	32.7	39.3
80 (49.7)	21.6	28.6	34.2
90 (55.9)	19.2	25.3	30.3
100 (62.2)	17.2	22.8	27.2
110 (68.4)	15.7	20.7	24.7
120 (74.6)	14.4	18.9	22.6