PERFORMANCE OF CURRENT SAFETY HARDWARE FOR *NCHRP REPORT 350* VEHICLES

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Since its publication in 1980, *National Cooperative Highway Research Program (NCHRP) Report 230*, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," (*1*) has served as the primary reference for full-scale crash testing of roadside safety features. However, significant changes in the vehicle fleet, and continued evolution in design concepts and technology necessitated an update to *Report 230*. A comprehensive update of the procedures for safety performance evaluation of highway features was published as *NCHRP Report 350* (*2*) in 1993. This document contains a wider range of recommended tests for evaluation of a wider range of roadside safety appurtenances including longitudinal barriers, terminals, crash cushions, breakaway support structures and utility poles, work zone traffic control devices, and truck-mounted attenuators.

DESIGN TEST VEHICLES DEFINED IN *REPORT 350*

The test conditions used for evaluation under the basic test level, test level (TL) 3, in *Report 350* are fundamentally the same as those as those used in *Report 230* with small differences in impact speed attributed to the hard conversion to SI units of measurement. For instance, the impact speed for TL-3 is 100 km/hr or 62 mph which is slightly greater than the 60 mph nominal test speed used under *Report 230*. The greatest departure between *Report 350* and its predecessor lies in the definition of its standard test vehicle. Although *Report 350* defines several supplemental test vehicles as the basis for optional testing at higher performance levels, most of our current hardware has been designed and tested to the equivalent of the basic test level, TL-3. *Report 350* specifies the use of a 3/4-ton pickup truck, designated 2000P, as the new design vehicle for evaluating structural adequacy under TL-3. This vehicle replaces the 4,500 lb passenger sedan (4500S) used under *Report 230* and is intended to represent the class of "light trucks" (vans, mini-vans, pickup trucks, utility/sport vehicles) which comprise a significant and growing portion of the vehicle fleet.

In order to assess the performance of the 2000P pickup upon impact with current roadside hardware, it is helpful to understand the differences in characteristics between the 2000P and 4500S passenger sedan, and how these differences may affect impact behavior. A comparison of the overall dimensions of these two design vehicles is shown in Table 1. The dimensions shown for the 4500S are average values obtained from vehicles used in full-scale crash tests conducted in accordance with *Report 230* requirements. The properties shown for the 2000P are average values for 3/4-ton pickup trucks obtained from crash tests, parking lot surveys, and the literature. As shown in Table 1, the overall length, width, and track width of these two vehicle classes are very comparable. There is approximately a 10 percent difference in wheelbase and, not surprisingly, there is a significant difference in overall height.

Some of the major differences between the 2000P and 4500S which are potentially very significant in terms of influencing impact behavior are summarized in Table 2. Center of gravity (c.g.) height of a 4500S passenger sedan is approximately 22 in., whereas the 2000P pickup truck has an average c.g. height of 28 in. With regard to bumper height, the 4500S typically averages 12.5 in. to the bottom of the bumper and 21 in. to the top of the bumper. In comparison, typical bumper heights for the 2000P average 18.5 in. to the bottom and 28 in. to the top. The average front overhang of a typical 4500S passenger sedan is 43 in. whereas the front overhang on the 2000P pickup is only 31 in.

These differences in vehicle characteristics can have a significant effect on impact performance with certain roadside features, and little, if any, effect on others. With regard to flexible longitudinal barriers, the impact performance is expected to degrade. The higher c.g. height of the 3/4-ton pickup renders the vehicle less stable and more susceptible to rolling on top of or over the barrier. Higher bumper height increases the potential for the bumper of the 2000P vehicle to override the rail element, thus increasing the propensity for vaulting. Furthermore, the shorter front overhang of the pickups increases the degree of interaction between the front tire of the vehicle and the barrier components which results in a greater tendency to climb the face of a barrier. This is particularly true for strong-post guardrail systems such as the G4(1S) and G4(2W),

TABLE 1 TYPICAL OVERALL DIMENSIONS OF DESIGN TEST VEHICLES

Vehicle Property	2000P	4500S
Length, in.	214	219
Width, in.	78	76
Height, in.	73	56
Wheelbase, in.	132	120
Track Width, in.	66	62

TABLE 2 PERTINENT PROPERTIES OF DESIGN TEST VEHICLES

Vehicle Property		2000P	4500S
C.G. Location, in.	above ground	28	22
	aft of front axle	61	51
Bumper Height, in.	top	28	21
	bottom	18.5	12.5
Front Overhang, in.		31	43

where significant wheel contact with the guardrail posts can occur prior to any significant redirection of the vehicle. For transitions from flexible to rigid barriers, such as occur at a bridge end, this additional wheel interaction attributed to the short front overhang can result in more severe wheel snagging and greater vehicular decelerations.

The increased c.g. height and shorter overhang of the 2000P are also potentially detrimental to its impact performance with commonly used rigid barriers such as the concrete safety shape. The shorter front overhang distance allows the front tire to interact more readily with the face of the barrier, potentially resulting in increased vehicle climb. This behavior, combined with the increased c.g. height of the vehicle, could increase the propensity for rollover.

The geometrics and increased frontal stiffness of the 3/4-ton pickup may pose a problem for some energy-absorbing devices such as crash cushions and truck mounted attenuators (TMA). Since a pickup truck has a stiffer front end than a passenger car, it will not absorb as much energy during a frontal impact. This behavior can be detrimental for devices which are at or near the required performance limits. In addition, the increased bumper and c.g. heights of the 2000P pickup may increase the propensity for overriding or vaulting during frontal impacts with some crash cushion or TMA designs.

For some roadside features, such as breakaway luminaries and sign supports, work zone features, and traffic control devices, the small 1800 lb (820 kg) passenger car is typically the critical test vehicle. Since the test conditions for this vehicle remain essentially the same, the implementation of *Report 350* should have little impact on these devices. Little difference in impact performance with pickup trucks is expected other than a somewhat increased potential for rollover during post-impact trajectory.

CRASH TEST EXPERIENCE

Although much remains to be learned regarding the safety performance of roadside features with the 2000P test vehicle, some testing has been conducted with pickup trucks from which preliminary assessments can be drawn. Much of our current knowledge regarding the impact performance of pickups stems from bridge

rail tests conducted in accordance with the requirements of the 1989 AASHTO *Guide Specification for Bridge Rails* (*3*). The test matrix for a performance level (PL) 2 railing includes a 5400 lb pickup truck impacting at 60 mph and 20 degrees. Although the test vehicle description contained in the *Guide Specification* specifies parameters such as wheelbase and c.g. height, it does not indicate whether the pickup should be a 1/2-ton or 3/4-ton design.

Bridge Rails

Several concrete, steel, and combination bridge railings were tested to performance level two (PL2) of the AASHTO *Guide Specification* under a recently completed FHWA Pooled Fund study which was conducted at TTI (*4*). The railings that were tested include:

- 32-in. vertical concrete parapet;
- 32-in. New Jersey safety shape;
- 32-in. F-shape;
- Illinois 2399-1 (steel post and tubing mounted on 7-in. curb);
- BR27C (steel post and tube mounted on 24-in. concrete parapet); and
- Illinois side mount (steel post and tubing mounted on side of deck).

Although not stipulated in the *Guide Specification*, all of the tests were conducted with a 3/4-ton pickup ballasted to 5400 lb. In each test, the pickup truck was redirected in a stable manner and the performance was considered to be satisfactory. However, it should be noted that the lateral kinetic energy that must be managed in a 5400 lb/60 mph/20 deg impact is 25 percent less than that resulting from a 4409 lb/62 mph/25 deg impact as required under test level (TL) 3 of *Report 350*.

More recently, several concrete barrier systems, both rigid and portable, were tested with the 2000P design vehicle of *Report 350*. In one study, a standard New Jersey concrete safety-shaped barrier connected to a bridge deck with 1 1/4 in. steel pins was successfully tested with a 2000 kg, 3/4-ton pickup truck impacting at a nominal 100 km/h and 25 degrees (*5*). Although the barrier was not completely rigid, the results of these tests and tests of other safety-shaped barriers with the 5400 lb pickup appear to indicate that the widely used safety-shaped barrier provides acceptable performance for test level 3 of *Report 350*.

A 32-in. tall single-slope concrete bridge rail was also successfully tested with the 2000P vehicle under test level 3 of *NCHRP Report 230* (*6*). Although the vehicle became completely airborne and the amount of climb was substantial, the vehicle remained upright and stable, and the test was judged to be a success.

In another study, a low-profile portable concrete barrier was developed and tested (*7*). This barrier, which is 20 in. in height and has a negative slope on the traffic face, was successfully tested with a 3/4-ton pickup at 45 mph and 25 degrees, which is nominally equivalent to test level 2 of *Report 350*. It is of particular interest to note that almost immediately after impact, the bumper of the pickup truck overrode the top of the 20-in barrier, yet the vehicle was still smoothly redirected. This may be at least partially attributed to the negative slope on the face of the barrier.

Based on these results, it seems reasonable to conclude that most of our common bridge rail systems will perform adequately with the 2000P vehicle when evaluated under *Report 350* criteria.

Guardrails and Transitions

Crash test experience with pickup trucks impacting flexible barriers is much more limited than that for bridge rails, and the testing that has been performed has yielded mixed results. A 32-in. high nested thrie beam transition with 3 ft-1 1/2 in. post spacing and W6x15 posts successfully passed a test with a 5400 lb pickup impacting at 60 mph and 20 deg. This test was conducted under the FHWA pooled fund study mentioned previously.

Undesirable behavior was observed when a 2,000-kg (4,409-lb) pickup truck impacted a strong-post W-beam guardrail system with 12 ft-6 in. post spacing at a nominal speed and angle of 45 mph (72.5 km/h) and 25 degrees (*8*). The bumper of the pickup truck overrode the W-beam rail element shortly after impact. It should be noted that the top of the bumper was at a height of 27 in. which placed it at the same height as the W-beam rail. Prior to any significant redirection of the vehicle, the vehicle pocketed at the first post immediately downstream of impact. The short front overhang of the pickup allowed the front tire to impact the post and load the front suspension. The vehicle subsequently vaulted the rail with virtually no damage to the vehicle or barrier.

In a test conducted as part of an earlier FHWA study which evaluated the performance limits of guardrails, median barriers, and embankments for different classes of vehicles and impact conditions (*9*), a Ford F150 pickup impacted a standard G4(1S) guardrail system at 56.9 mph and 23.5 degrees. The 1/2-ton pickup had a

weight of 3,834 lb, a c.g. height of 26.1 in., and a bumper height of 21.5 in. During the impact, the tire of the vehicle snagged severely on the second post downstream from the point of impact and the vehicle achieved a maximum roll angle of about 35 degrees before being redirected.

Other experience with flexible barriers is largely comprised of a recently completed study which evaluated special roadside features and geometry such as guardrails behind curbs, guardrails on curves, and guardrails on slopes (*10*). The tests conducted under this study were conducted with either a 1/2-ton or 3/4-ton pickup truck ballasted to 5,400 lb and impacting at a nominal speed and angle of 60 mph and 20 degrees, respectively. In this study, a G4(1S) installed on a 6:1 downslope successfully redirected a 3/4-ton pickup truck. The maximum roll angle was reported to be 15 degrees. A 3/4-ton pickup was also successfully redirected by a G4(1S) placed on a 1,192-ft radius curve. Since the curve tends to effectively increase the angle of impact and, hence, the impact severity, the results of this test are somewhat encouraging. However, this same installation with a 10 percent superelevated roadway section and 2 percent upsloping shoulder failed to redirect a 1/2-ton pickup. A subsequent test on a modified thrie beam guardrail with the same geometry successfully redirected a 1/2-ton pickup truck.

Other tests performed in this study evaluated the performance of curbs placed in front of a standard G4(1S). In a test with an 8-in. curb, a 3/4-ton pickup impacting at 60 mph and 20 degrees, vaulted the barrier in much the same manner as observed in the test of the low service level, 12 ft-6 in. guardrail system described above. When evaluated with a 4500-lb 1/2-ton pickup impacting at 45 mph and 25 degrees, a G4(1S) with a 6-in. curb also failed to redirect the vehicle.

Limited testing of other appurtenances was conducted in another study which evaluated the initial feasibility of replacing the 4,500 lb passenger sedan with a 5,400 lb pickup truck (*11*). As part of this assessment program, a G4(1S) was tested with a 5,400 lb pickup impacting at 65 mph and 20 degrees. These impact conditions generate an impact severity roughly equivalent to a 4,500 lb car impacting at 60 mph and 25 degrees. A 1/2-ton pickup truck with a bumper height of 21.5 in. was used for this test. The pickup was successfully redirected with a maximum reported roll angle of approximately 20 degrees. Although this test was successful, it is difficult to extrapolate the safety performance of the G4(1S) with a 3/4-ton pickup which has a much greater bumper and c.g. height.

Although definitive tests have not been conducted to date, these results raise concern regarding the capabilities of our widely used W-beam guardrail systems to contain and redirect the 2000P test vehicle under TL-3 of *Report 350*.

Crash Cushions and Attenuators

Generally speaking, tests of crash cushions and energy-attenuating devices with pickup trucks have had satisfactory results. A Fitch sand barrel attenuating system successfully passed a test with the 2000P head-on at 100 km/h (*12*). On the other hand, two previous tests with Energite sand barrels impacted by a 1/2-ton pickup ballasted to 5,400 lb and impacting a speed of 55 mph were unsuccessful due to vehicle ramping (*11*). However, there was some concern expressed in regard to these failures that the properties of the 1/2-ton pickup may have been significantly altered by the large amount of ballast required to achieve a test inertial weight of 5,400 lb.

Other crash cushions such as the vehicle attenuating terminal (VAT), the Connecticut impact attenuating system (CAIS), and the GREAT (Guardrail Energy Absorbing Terminal), have all reportedly passed tests with a 5,400 lb pickup at a nominal speed of 55 mph (11). In terms of kinetic energy, these impact conditions are equivalent to a 4500 lb vehicle impacting at 60 mph.

Although the data are limited, it appears that most currently approved designs will satisfy *Report 350* requirements for end-on impacts. However, as discussed previously, the geometrics of the 3/4-ton pickup may increase the propensity for vaulting for certain designs.

Other Appurtenances

A few other miscellaneous appurtenances have also been tested with pickup trucks. A test with an eccentric loader terminal (ELT) was judged as marginally passing (*11*). The test involved a 1/2-ton pickup ballasted to 5,400 lb impacting at a speed of 51 mph. During the test, the vehicle ramped and achieved a maximum roll angle of 43 degrees. In another test, a bull-nose median barrier terminal was found to exhibit acceptable impact performance when impacted by a 5,400 lb pickup at 55 mph and 0 degrees (*11*).

SUMMARY

A summary of the tests described above is presented in Table 3. As shown in this table, most of the crash tests with pickup trucks that have been performed to date have involved a full-size pickup ballasted to 5,400 lb. Since some of these tests involved a 1/2-ton vehicle, and since the impact conditions typically used in conjunction with the 5400-lb test vehicle result in a significantly lower impact severity than those required by test level 3 of *Report 350*, it is difficult to make conclusive assessments regarding the ability of some of these systems to meet *Report 350* criteria. However, these

TABLE 3 SUMMARY OF CRASH TESTS CONDUCTED WITH PICKUP TRUCKS

System Tested	Vehicle Description		Impact Conditions		Comments
	Type	Weight (lb)	Speed (mph)	Angle (deg)	
Bridge Rails					
32-in. Vertical Parapet	3/4 ton	5797	59.7	20.5	passed
32-in. N.J. Safety Shape	3/4 ton	5724	57.7	20.6	passed, 23 in. climb
	1/2 ton	5408	65.0	19.0	passed, 11 deg. roll
32-in. F-Shape	3/4 ton	5780	65.4	20.4	passed, 20 deg. roll
Illinois 2399-1	3/4 ton	5797	63.6	20.9	passed
BR27C	3/4 ton	5570	58.3	19.6	passed
Illinois Side Mount	3/4 ton	5565	60.4	20.4	passed
32-in. Constant Slope	3/4 ton	4573	60.4	25.5	passed, 30 deg. roll
Concrete Beam and Post	3/4 ton	4500	61.9	25.6	passed
Guardrails and Transitions					
Nested Thrie Transition	3/4 ton	5750	62.7	19.0	passed
G4(2W), 12'-6" post spacing	3/4 ton	4409	43.2	24.5	failed, vehicle vaulted
G4(1S)	1/2 ton	3834	56.9	23.5	marginal, 35 deg. roll
	1/2 ton	5390	65.9	18.8	passed, 19 deg. roll
G4(1S), 6:1 downslope	3/4 ton	5710	59.7	20.0	passed, 15 deg. roll
G4(1S), 1,192-ft radius	3/4 ton	5712	61.1	20.0	passed, 20 deg. roll
G4(1S), 1,192-ft radius, 10% superelevation	1/2 ton	5727	60.9	20.0	failed, vehicle rolled
Modified Thrie, 1,192-ft radius, 10% superelev.	1/2 ton	5743	61.0	20.0	marginal, 45 deg. roll
G4(1S), 8-in. curb	3/4 ton	5742	61.3	20.0	failed, vehicle vaulted
G4(1S), 6-in. curb	1/2 ton	4562	46.1	25.0	failed, vehicle intrusion
Crash Cushions and Attenuators					
Fitch Sand Barrels	3/4 ton	4500	60	0	passed
Energite Sand Barrels	1/2 ton	5400	54.7	0.3	failed, vehicle ramped
VAT	1/2 ton	5420	54.3	1.9	passed
CAIS	1/2 ton	5387	56.8	1.5	passed
GREAT	3/4 ton	5573	54.8	11.1	passed
Other Appurtenances					
ELT	1/2 ton	5722	51.4	0.2	marginal, 43 deg. roll
Bull-Nose Median Terminal	1/2 ton	5390	54.9	0.1	passed

tests do provide considerable insight into the safety performance of current hardware with the 2000P test vehicle from which some general conclusions can be drawn.

Certain roadside features such as breakaway devices, small sign supports, and traffic control devices should not be a concern from the standpoint of occupant risk. However, the potential for occupant compartment intrusion with some designs may warrant further investigation.

It appears that most of the common rigid barriers and bridge rails such as the New Jersey safety shape, F-shape, vertical wall, and constant-slope barrier will satisfy the requirements of test level 3 in *NCHRP Report 350*. The results of tests on crash cushions appear to indicate a strong potential for good impact performance.

The most critical area of concern appears to be the performance of widely used flexible barriers with the 2000P. The short front overhang and increased c.g. and bumper heights of the 3/4-ton pickup significantly increase the potential for vaulting and rollover during impacts with many standard guardrail systems.

Further research is clearly warranted to better quantify the safety performance of roadside features with the 2000P pickup truck and other subclasses of light trucks, particularly for flexible barrier systems. Since the 2000P will be the design test vehicle of the future, it should also be established whether or not it is an appropriate surrogate for the other vehicles it is intended to represent.

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