E. Crash Test Conditions and Tolerances

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This presentation examines and takes issue with some of the specified crash test conditions and tolerances as outlined in NCHRP Report 230 and the new guide specifications for crash testing of bridge railings. It is not possible to cover many items within this short period of time, so I will just highlight a few items to stimulate more thought and discussion on this topic during this meeting.

Impact Speed and Angle

NCHRP Report 230 specifies tolerance on the impact condition using the composite term of impact severity, IS, which is defined as:

$IS = 1/2m(v \sin \Theta)^2$ where:

m = vehicle test inertial mass in slugs,
v = impact speed in feet per second, and
Θ = impact angle in degrees.

The tolerances are even tighter on the new bridge rail guide specifications with -1.0 and +2.5 mph on the impact speed.

For a reverse tow and cable guidance system used for passenger cars and light trucks, the impact angle can be well controlled and meeting the specified angle is generally not a problem. Impact speed is somewhat harder to control, depending entirely on the skill of the driver in the towing vehicle. Thinking of our everyday driving, it is not easy to maintain a constant speed even with cruise control.

Now for the driver of the towing vehicle, he has to be concerned first with getting the test vehicle up to speed. Any surface discontinuity, such as a slick spot or an uneven pavement joint, could cause the towing vehicle to temporarily lose traction and speed. He also has to be concerned with exceeding the desired speed since slowing down of the towing vehicle could introduce slack into the tow cable and temporary loss of control on the vehicle being towed.

The problem is much worse for tractor-trailers and other heavy vehicles tested under their own power, using a radio remote control system. Here a push truck is first used to accelerate the test vehicle up to 35-40 mph. The clutch and throttle of the test truck are then engaged and the vehicle continues accelerating to the desired speed. A governor is usually used to control the top speed of the test vehicle. The test truck is steered using radio remote control by an operator in a chase car.

It is not difficult to see that a lot can go wrong with this system that could result in the impact speed or angle not meeting the specifications. I will just mention a few that we have unfortunately experienced: loss of contact between the push and test vehicles due to yawing of test vehicle as the clutch and accelerator were engaged, sudden unexplained loss of engine power in the test vehicle, interference in the radio frequency, and failure of an electronic component in the remote control unit. The change from a tail wind to a head wind situation could significantly affect the acceleration ability of the test vehicle and result in the difference of 3 to 4 mph in the impact speed. Everything has to work properly in order to meet the specified tolerances.

Point of Impact

Control for point of impact is no problem with a reverse tow and cable guidance system, but an area of concern for the remote control system. At an impact angle of 15 degrees, one foot variation in the path of the vehicle means four feet difference in the point of impact. This could be important for a post-and-beam type of barrier. Another situation in which a slight error in the point of impact could have significant effect is with testing of multi-leg sign supports. Because of the requirement that all legs of the sign support must be impacted simultaneously, along with the narrow track width of an 1,800-pound car, a slight offset in the impact point could result in a large difference in forces acting on each of the sign supports, rotation in the vehicle, or even damage to tires from the stubs in the ground.

Another issue is on what is the appropriate point of impact for various appurtenances. For beam-and-post longitudinal barriers, one of the concerns is for snagging and/or pocketing. The critical impact location in this case would be the point at which the potential for snagging is maximized. Impacting too close to the snag point would allow a vehicle to clear the snag point before guardrail deflections and vehicle penetration become large enough to allow snagging and/or pocketing. On the other hand, impacting too far upstream from a snag point may allow sufficient vehicle redirection before the snag point is reached. It should also be noted that the critical impact point changes with the stiffness of the barrier.

For example, the specified point of impact for a transition is 15 feet upstream from the more rigid system. Computer simulation and prior crash test results indicate that the critical location for a W-beam guardrail system is at a distance of 7 to 8 feet upstream from the more rigid system. Another example is on a concrete beam and post bridge rail system. When impacted near a post, the vehicle was smoothly redirected and the bridge rail successfully passed the NCHRP Report 230 evaluation criteria. However, when a very similar system was impacted further upstream from a post to maximize the potential for snagging, severe wheel and hood snagging were observed.

Soil Condition

The soil type and embedment practice have major effects on the performance of "breakaway" sign supports and, to a lesser extent, on longitudinal barrier systems. The use of the strong soil (S-1) is probably reasonable for many safety appurtenances. Even so, the depth, surface radius of embedment material, and soil moisture content are some topics that need to be further evaluated.

The weak soil (S-2) is much more of a problem. For example, NCHRP Report 230 specifies 2 to 10 percent of fines passing the No. 100 sieve for the weak soil with no mention of cohesiveness. We have been using river bottom sand with a fines content of 4 percent for our weak soil pit and the soil has little cohesion and very low resistance. By increasing the fines content to 10 percent with clayey material (still within the limits of the specification), the soil will have very high cohesion and resistance. The soil moisture content can drastically affect the soil strength since the clayey material has virtually no strength when saturated, but very high strength when dry.

Test Vehicle Properties

In NCHRP Report 230, the properties of test vehicles are specified in terms of mass, mass moments of inertia, and certain basic dimensions. Even with the guidelines, tests of two "identical" cars on the same appurtenance may have significantly different results due to variations in such vehicle factors as chassis alignment, suspension system, shock absorbers, tires, etc. Thus, to reduce variability introduced by the test vehicles, one may want to tighten the specifications on the test vehicle, perhaps even to the point of specifying vehicle years, makes and models.

The new bridge railing crash test matrix is much more specific in terms of the test vehicle properties, which is understandable in efforts to improve the repeatability of crash tests. However, it is also important to make sure that the specifications are such that the test vehicle represents a common class of vehicles on the highway and can thus be purchased readily and economically. In my opinion, the new bridge rail specifications failed to meet this requirement. We have great trouble in locating vehicles that fit the specifications and, on several occasions, had to physically alter some vehicle properties in order to meet the specifications. For example, we had to move the axle locations on several trucks to meet the wheelbase requirements.

Needless to say, this greatly increases the cost for acquiring the test vehicles which is a major cost factor in crash testing. A balance has to be attained between specificity and repeatability and costs involved in meeting the specifications.

Instrumentation

Instrumentation is another area that needs to be considered. For instance, 50-g accelerometers are used due to the high-g environment of the crash testing conditions. A one-percent accuracy, which is good accuracy, means the difference of 0.5 g which is fairly insignificant by itself. However, for a sign test, 0.5 g over duration of the impact, e.g., 150 milliseconds, could mean a velocity change of 2.4 feet per second, which is 16 percent of the acceptance threshold of 15 feet per second.

Another example is the number and placement of accelerometers and possibly rate gyros. Currently, one set of accelerometers is typically placed near the vehicle c.g. to measure longitudinal, lateral and vertical components of accelerations. Data from these measurements are then used to compute changes in vehicle velocity and occupant impact velocities from the flail-space model. For impacts with longitudinal barriers or other features that cause the vehicle to undergo rapid changes in angular position, major errors can occur in the computation of vehicular velocity change and occupant impact values. The errors increase as the distance from the accelerometer position to the c.g. increases. It should be pointed out that it is often difficult to place the accelerometer at the vehicle c.g. due to seat locations and/or the structural aspects of the test vehicle.

Discussions

Finally, there are three specific points that I would like to bring up regarding future consideration and determination of the crash test conditions and tolerances.

First, the crash test conditions and tolerances should be determined on the basis of cost-effectiveness considerations. On the one hand, we would like to minimize any vagueness or ambiguity in the specifications to assure uniformity and consistency among all testing agencies so that the test results are more precise and repeatable. On the other hand, it is important to bear in mind the economics of tightening the specifications and the economic burden placed on the highway agencies designing and developing new or improved roadside safety appurtenances. The state-of-the-possible may not necessarily be economically feasible. A balance has to be struck between these two conflicting goals to come up with a balanced set of specifications.

Secondly, despite the considerable amount of crash testing done in the past twenty-five or so years, there is still a lack of information on the effects of the various test conditions on the results of the crash tests. For example, how important is the difference of three miles per hour from the target impact speed of 50 miles per hour? We had the misfortune of finding that out. A test was repeated three times because the impact speed was three miles per hour lower than the target speed in the first two tests. From the standpoint of the vehicle dynamics, there was hardly any difference between the three tests. From the standpoint of force or loading on the barrier, the higher speed impact did have higher force or loading as expected, but the difference was roughly proportional to that between the squares of the impact speeds. Could the results from the lower speed impact be extrapolated to the target speed and avoid the expense of rerunning the test? I think that these are some of the questions that we need to address in establishing the tolerances for the various test conditions.

The third and perhaps the most important point concerns the purpose of crash testing. I think there is one underlying philosophical issue that must be addressed first. If the purpose of crash testing is to conduct research and development, we can probably afford greater variance in the test conditions and tolerances and to test for the worst case scenario. If the test purpose is to demonstrate the prototype device at the "certification" level, we may want to tighten the specifications since it would not be to the advantage of the agency to test at the worst possible condition. Unfortunately, these two purposes are oftentimes at odds with each other.

Take testing of a transition design as an example. The specified point of impact is 15 feet upstream from the more rigid system, but the most critical point of impact may be 8 feet upstream from the more rigid system. If the test purpose is strictly research and development, the point of impact should be the most critical location, or 8 feet upstream. However, if the purpose is also "compliance," then it would be to the benefit of the agency to use the specified point of impact, or 15 feet upstream. Testing at the more critical point could result in unacceptable performance and hence rejection of the appurtenance.

In summary, I have outlined a few areas under the general topic of "Crash Test Conditions and Tolerances" that I believe need further consideration as the NCHRP Report 230 requirements are being updated. These are by no means inclusive and they are intended to stimulate more thoughts and discussion on this topic during this workshop. I am sure that many more topics and issues will be raised during the course of this workshop that would benefit the update of the NCHRP Report 230 requirements.