PRELIMINARY RECOMMENDATIONS FOR PERFORMING SIDE IMPACT CRASH TESTS OF ROADSIDE SAFETY FEATURES

Malcolm H. Ray
Worcester Polytechnic Institute
100 Institute Road
Worcester, MA 01609

March 8, 2000

TABLE OF CONTENTS

1 SCOPE 1
1.1 Test Articles 2
1.1.1 Installation 2
1.1.2 Site Details 3
1.2 Test Vehicles 3
1.2.1 General Vehicle Requirements 3
1.2.2 Test Vehicle Characteristics 3
1.3 Anthropometric Test Device 4
1.3.1 Type 4
1.3.2 Instrumented ATD (Optional) 5
1.3.3 Position 5
1.4 Propulsion Method 6

2 IMPACT CONDITIONS 6
2.1 Impact Velocity 6
2.2 Impact Angle 7
2.3 Impact Point 8

3 DATA ACQUISITION 8
3.1 Electronic Instrumentation 8
3.1.1 Vehicle Data 9
3.1.2 Roadside Hardware Test Device 10
3.1.3 Anthropometric Test Device 11
3.2 Photographic Data 11
3.2.1 Still Photography 11
3.2.2 Motion Photography 12

4 EVALUATION 13
4.1 Vehicle Criteria 13
4.1.1 Rollover 13
4.1.2 Post-Impact Trajectory 13
4.1.3 Emergency Exit 13
4.1.3 Debris-Free Traveled Way 14
4.2 Occupant Criteria 14
4.2.1 Head Impact Criteria 15
4.2.7 Normalizing ATD Position 16

5 REPORTING AND DOCUMENTATION 17

6 REFERENCES 17

PRELIMINARY RECOMMENDATIONS FOR PERFORMING SIDE IMPACT CRASH TESTS OF ROADSIDE SAFETY FEATURES

Malcolm H. Ray
Worcester Polytechnic Institute
Worcester, MA 01609

1 SCOPE

The following sections provide recommendations for performing side impact crash tests of roadside safety hardware. Side impacts, as defined in this document, refer to collisions that occur at relatively high impact angles (e.g., between 30 and 150 degrees) along the side of a vehicle that slides sideways into a hazardous object. In general such impacts have a high potential for extensive and sever occupant compartment intrusion. The objective of performing such tests is to assess the risk of occupant injury in similar real-world collisions. Side impact crash tests are a design tool for developing roadside hardware that will minimize the risk to vehicle occupants in side impact collisions.

These recommendations are supplementary to the recommendations given in NCHRP Report 350 for full-scale crash testing of roadside safety hardware.*(4)* Roadside hardware must satisfy the recommendations of Report 350 prior to consideration for use in field installations. These recommendations provide a supplementary means of assessing the effectiveness of roadside hardware in side impact collisions. At this time there are no specific requirements for side impact performance necessary before a roadside safety device can be installed in the field.

Commentary

Each year about 225,000 people are involved in side-impact collisions with roadside objects like trees utility poles and guardrail terminals.*(1)* It has been estimated that the societal cost of side impact collisions with fixed roadside objects exceeds three billion dollars annually.*(2)* One in three vehicle occupants involved in side impacts with roadside objects are injured and one in one hundred is fatally injured.

Side impacts with roadside objects are a significant cause of human trauma and improved roadside hardware design can help to alleviate that suffering. Developing roadside hardware with better side impact performance is an emerging factor in improving roadside safety in the next decade. The purpose of performing side impact crash tests is to assess the risk of injury to vehicle occupants in the event of a side impact collision and to develop techniques for minimizing this risk. The purpose of this document is to present recommendations for performing side impact crash tests of roadside hardware.

An earlier version of these recommendations has appeared in a Federal Highway Administration (FHWA) Technical Report as well as in Appendix G of NCHRP Report 350.*(3) (4)* A commentary of these recommendations along with a description of tests performed according to these recommendations has been published in the Transportation Research Record series.*(5)*

These recommendations have been developed with the intent to be as consistent with NHTSA's FMVSS 214 standard and other side impact crash testing standards as is possible while still providing information useful for evaluating roadside hardware devices.*(13)* Many of the specific requirements were taken directly from either the FMVSS 214 Standard or the FMVSS 214 Test Procedures.*(6)*

1.1 Test Articles

These recommendations apply to all narrow roadside objects principally:

- Luminaire supports,
- Guardrail terminals,
- Utility poles,
- Narrow crash cushions and
- sign supports.

In additional to the roadside safety hardware listed above it may be of interest to also perform side impact crash tests of other roadside features like trees and utility poles since these objects have been disproportionally linked to severe and fatal injury accidents.

Commentary

An examination of the National Accident Sampling System (NASS) and Fatal Accident Reporting System (FARS) indicate that narrow roadside objects like trees, poles, luminaire supports and guardrail terminals are much more likely to be associated with fatal and serious injury accidents than other types of broad roadside features.*(2)* Narrow objects subject the side structure of a vehicle to a more concentrated loading with associated higher risk of injury to vehicle occupants.

The most serious side impact problems indicated by accident data are impacts trees, utility poles, luminaire supports and guardrail terminals, respectively.*(2)* In principal side impacts with small sign supports could also be a problem but perhaps because of their small mass and generally good frontal impact performance they have not appeared to be a problem in the accident data. Likewise, collisions narrow crash cushions could in principle be serious side impact events but perhaps because of their energy absorbing capacity and good frontal performance they have not appeared to be a large problem in the field.

1.1.1 Installation

Test devices shall be installed as they normally would be installed on the roadside. This includes details pertaining to the construction and layout of the device, its position and location with respect to the hypothetical roadway, the side-slope geometry, the surface conditions and the soil conditions where appropriate.

Commentary

Test devices should be installed at the test site in the same way that they are installed in the field to ensure that the results are relevant to actual real-world sites. If, for example, the device is generally installed on a slope in the field it should be tested using a similar slope.

1.1.2 Site Details

Relevant site details shall be recorded and documented in the test report. The geometry of the site showing the location of the device shall be included. Plans or drawings illustrating the features of the device shall be included in the test documentation. If the device is mounted in soil the density of the soil and the moisture content on the day of the test shall be recorded and documented in the test report.

Commentary

Site details are often important features of the device and adequately documenting the characteristics of the test installation is essential for subsequent analysis. All details that might have an affect on the performance of the device should be recorded in case anomalous results are observed during the test.

1.2 Test Vehicles

All vehicles used for side impact crash tests of roadside hardware shall be sedan vehicles satisfying the requirements of Section 1.2.2.

1.2.1 General Vehicle Requirements

The vehicle shall have the manufacturer's recommended standard tires and the tires shall be inflated to the manufacturer's recommended air pressure during the test. All doors shall be closed and latched but shall not be locked. The test vehicle impact-side window shall remain closed but the opposite (e.g., passenger side) window shall be in the open position to facilitate photographic coverage. Vehicles with automatic transmission shall be in "neutral" and manual transmission vehicles shall be in second gear during the test. The parking brake shall be set and left on during the test.

Commentary

Vehicle condition can affect the results of the test so it is important to document the condition of the vehicle prior to the test. The list of requirements in the second paragraph of Section 1.2.1 are included to standardize test conditions as much as possible by eliminating possible variations between tests. These requirements are identical to those given in the FMVSS 214 procedures manual.*(6)* For example, tires with abnormally low pressure may cause unrealistic vehicle rotations.

1.2.2 Test Vehicle Characteristics

Test vehicles for side impact crash tests shall be less than six years old at the time of the test. The vehicle model shall be one of the top two selling models during the year the vehicle was manufactured with a curb weight less than 1000 kg. The test vehicle must be a two-door front-wheel drive passenger vehicle in good repair with a curb mass of less than 1000 kg. The vehicle shall have no serious body damage and no significant rust or deterioration that would affect the structural integrity of the vehicle. In particular the floor, seat mounts, door and lower sills shall be carefully checked to verify their condition since these components are important load paths in a side impact collision.

Commentary

Accident data indicates that occupants of larger passenger vehicles are at similar risk to those in smaller passenger vehicles.*(7)* While this might suggest that the choice of a test vehicle is not particularly important, a specific type of vehicle has been selected for (1) standardization reasons and (2) to minimize the amount of impact energy available to activate the test device. To avoid constantly redefining the test vehicle based on the current fleet, the test vehicle is to be selected with respect to the number vehicles sold.

The curb mass is defined as the standard manufacturer's rated mass with all fluids but with not occupants or cargo. The test inertial mass is the mass of the vehicle in the test-ready condition no including the mass of any anthropometric test devices (ATD). Rigid ballast should take the form of steel plates bolted securely to the floor of the vehicle.

The 820C test vehicle is a standard roadside hardware crash test vehicle and should therefore be familiar to organizations already performing Report 350 crash tests. An 820-kg vehicle is one of the lowest mass vehicles commonly sold so it would result in the most demanding test for devices that require some minimum energy to activate. Common 820C vehicles like the Ford Festiva or GeoMetro would be acceptable models for test vehicles selected from the early to mid 1990's vehicle population.

The vehicle should have no damage that may compromise its performance in the side impact crash test. While obtaining a flawless test vehicle is preferred it is often the case that vehicles with some damage must be used. Insignificant damage would include dents smaller than 50 mm in diameter, paint scraps and scratches and surface rust (e.g., the rust has not penetrated the sheet metal).

When ballast is used it must be rigidly attached to the vehicle. The addition of ballast must not change the location of the center of gravity of the vehicle by more than 50 mm in any direction as compared to the pre-impact location of the center of gravity.

1.3 Anthropometric Test Device

1.3.1 Type

An anthropometric test device (ATD) is required in all side impact tests for inertial purposes. If the ATD is to be used to collect electronic data it shall conform to the requirements of Section 1.3.2. If the ATD is not going to be used to collect electronic data any type of 50^{th} percentile male ATD may be used.

Commentary

A 50^{th} percentile male seated in a small passenger can often account for more than 10 percent of the total mass of the vehicle so including an ATD in the driver position is important for obtaining a correct and meaningful kinematic response. Since the driver is positioned away from the vehicle center of gravity, the presence of the occupant changes all the inertial properties of the vehicle in addition to the mass.

1.3.2 Instrumented ATD (Optional)

The use of an instrumented ATD is optional though highly recommended. If an ATD is used to collect the occupant injury data it shall conform to the Part 572 Subpart F Side Impact Dummy (SID) with the exception that a Hybrid-III head and neck shall be substituted for the standard SID head and neck (e.g., the SID-H3).*(13)* The SID-H3 ATD shall be instrumented such that the head injury criteria (HIC), the thoracic trauma index (TTI) and the maximum pelvis acceleration (P_y) can be calculated as specified in Sections 4.2.1 through 4.2.3. The SID-H3 shall be calibrated and maintained as specified in the "SID User's Manual."*(6)*

Commentary

The part 572 Subpart F Side Impact Dummy (SID) is the oldest type of commonly used side impact ATD. It has been used in FMVSS 214 since the dynamic test was added in 1992 and has also been used as a research tool by NHTSA and the automobile manufacturers since the early 1980's.*(13)* The SID is not, however, the only side impact ATD available. Other devices like the BioSID and the EuroSID have been developed and are considered by some to be superior devices. The Part 572 Subpart F SID is used herein, however, in order to maintain a link with the occupant performance criteria in FMVSS 214.*(13)*

1.3.3 Position

The ATD, whether instrumented or not, shall be positioned in the driver's seat using the FMVSS 214 test procedures such the following FMVSS 214 requirements are satisfied:*(13, 6)*

- Thorax S7.1.1
- Pelvis S7.2
- Legs S7.3
- Feet S7.4

The seat shall be in the mid-range position in the front-to-back direction. The seat back shall be positioned in the first detent past a 25^{o} angle rearward of the vertical direction. All available seat belts and shoulder harnesses shall be used to restrain the ATD. If the vehicle is equipped with airbags, all airbags shall be disabled during the test.

Commentary

The ATD represents a 50th percentile male. Correctly positioning the SID-H3 ATD is important for obtaining consistent and repeatable occupant injury measures (e.g., TTI, HIC and pelvis acceleration). An ATD that is not in the correct position before the test will probably not be in the correct position at impact.

The objective is to place the SID-H3 in the position required by FMVSS 214. In a small two-door sedan this will generally result in the head form being in front of the B pillar with the hip point of the dummy near the center of the door. The impact point will be located such that the impact is centered on the SID-H3 hip.

1.4 Propulsion Method

The test vehicle may be accelerated to the desired target speed recommended in Section 2.1 using any appropriate method. Regardless of the propulsion method chosen, (1) the vehicle must be accelerated into the roadside hardware test article (e.g., the vehicle moves toward the stationary hardware), (2) the vehicle must slide laterally into the test device on its own tires and (3) there shall be no attachment between the propulsion system and the vehicle for at least 2 m prior to the impact .

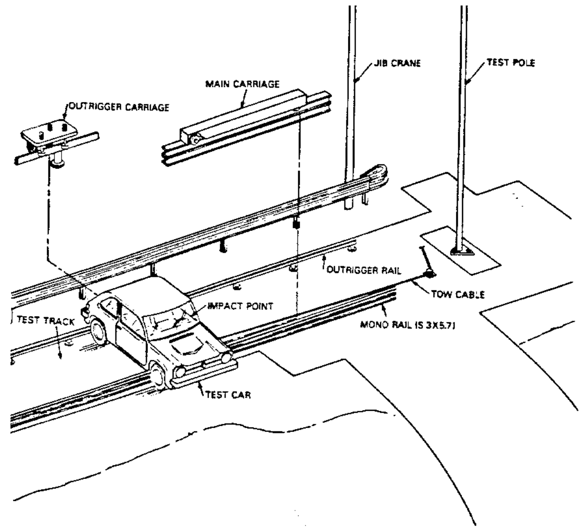

Figure 1. The Federal Outdoor Impact Laboratory side impact test facility.*(8)*

The surface area 2-m in front of the test article shall have a quasi-static coefficient of friction between 0.5 and 0.7. The quasi-static coefficient of friction shall be measured by attaching a load cell to a chain or cable connecting the underbody of a test vehicle to a pull-vehicle. The pull-vehicle shall slowly drag the test vehicle sideways such that the load cell measures the pulling force. The average coefficient of friction (e.g., vehicle weight divided by the pull force) shall be documented in the test report. The coefficient of friction need not be measured before every test but should be periodically measured to check the condition of the sliding surface.

Commentary

A variety of propulsion methods have been used in side impact crash tests although by far the most common method used for testing roadside safety hardware has been the gravity-accelerated laterally-mounted propulsion method used at the FHWA Federal Outdoor Impact Laboratory (FOIL) and shown in Figure 1.*(8)*

There are several other common propulsion methods used in full-scale crash tests in addition to the gravity-tow method used at the FOIL. The Swedish Road and Traffic Institute (VTI) performs side impact tests using a electrically powered high-torque fly-wheel inertial system that pulls the vehicle laterally on a common wooden pallette.*(9)* Texas Transportation Institute (TTI) has used a reverse-towed trolley system to perform a side impact crash test.*(10)* These and any other methods are acceptable as long as they satisfy the recommendations herein.

2 IMPACT CONDITIONS

2.1 Impact Velocity

The vehicle shall strike the test object at a lateral velocity of 50 km/hr ± 4 km/hr. The impact velocity shall be measured using either a high-speed camera or an electronic speed trap. The lateral velocity shall be measured after the tow mechanism is completely separated from the vehicle but before first contact between the vehicle and test device.

The yaw rate of the vehicle shall be less than 5 degrees/sec just prior to the time of impact as measured by the overhead high-speed camera positioned over the impact point. There shall be essentially no longitudinal component of velocity just prior to the time of impact.

Brakes shall not be applied until or unless there is complete separation between the impacted device and the vehicle after the impact.

Commentary

Investigation of the NASS and FARS data has indicated that 90 percent of side impact collisions with fixed roadside objects occur at a lateral velocity of 50 km/hr or less.*(7)* The velocity measurement must reflect the actual impact velocity to the extent possible. For this reason it is necessary that the vehicle be sliding freely when the measurement is taken. Generally vehicles come to rest still in contact with the test article in side impact collisions so braking will not usually be necessary. If braking is needed, however, it must not be applied while the vehicle is still interacting with the test device since this could potentially change the post impact response of the vehicle.

2.2 Impact Angle

The vehicle shall be oriented such that the forward direction of the vehicle is perpendicular to the longitudinal direction of a hypothetical the roadway and the front of the vehicle faces the hypothetical roadway. At the time of impact the side slip distance, S, shall be less than 300 mm as measured by the overhead high-speed camera located over the impact point. S is measured from the rear-most impact-side corner of the vehicle to the front-most corner on the impact side parallel to the hypothetical roadway as shown in Figure 2.

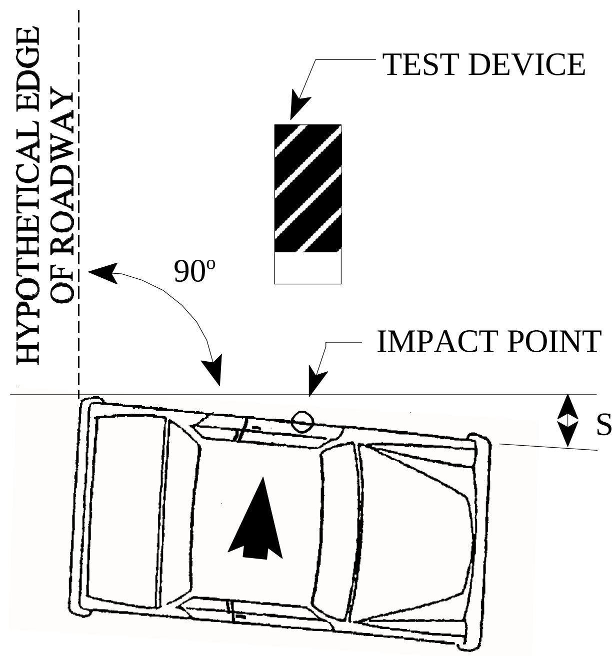

Figure 2. Side Impact Test Orientation .

Commentary

The impact angle in side impacts with roadside features can be crudely measured in the NASS accident data using the direction of force variable. Severe injuries (e.g., AIS>3) are most often associated with directions of force between 45 and 105 degrees from the front of the vehicle and 60 percent of all side impact collisions have angles in this range.*(11)* While the mean direction of force was approximately 60 degrees, the most frequently observed direction of force was 90 degrees.*(1)* A full-broadside collision is specified because it represents a very hazardous condition for vehicle occupants and is therefore a practical worst case impact scenario.

The purpose of measuring the side slip distance S is to ensure that the vehicle is essentially perpendicular to the hypothetical roadway. The typical 820C vehicle is 3700 mm ± 200 mm long according to Section 1.2.1. If the distance S, measured parallel to the hypothetical roadway, is less than 300 mm the yaw angle at impact will be less than 5º.

2.3 Impact Point

The impact point shall be located on the driver-side door at the location where the adjustment wrench is inserted into the hip of the ATD. This will generally correspond to a point near the center of the impact-side door for typical small two-door passenger sedans.

A nail, sharpened welding rod or some other sharp pointed object shall be placed at the center of the roadside hardware device such that it will punch a hole in the side of the vehicle at the point of impact. The actual impact point as measured by the puncture in the vehicle door must be no more than ±50 mm from the intended impact point. The intended impact point shall be clearly marked on the vehicle with paint or a stick-on target.

Commentary

The center of the door is considered to be the weakest point on the door since the bending moment is maximized at this location. In most small passenger vehicles the center of the door will be located near a point on the driver between the knee and the hip. Occupants are at higher risk when the impact occurs on the passenger door.*(11)* The location corresponding to the peak risk is at the location where the occupant's head and hip would be in a typical small two-door passenger car.*(1)* The intent is to place the impact point at the same location with respect to the ATD in each test even though the location with respect to the door may vary. The impact point is easily determined by inserting the ATD adjustment wrench into the hip adjustment bolt when the driver side door is open and the ATD has been positioned in the seat. A string and plumbob can be attached to the end of the wrench and a reference point marked on the sill of the vehicle. The impact point is then defined as a vertical line passing through this reference point.

3 DATA ACQUISITION

Two types of data shall be collected before, during and after the test: (1) photographic data and (2) electronic data.

3.1 Electronic Instrumentation

All electronic instrumentation shall conform to the recommendations of SAE J211 expect where specifically stated otherwise in the following sections.*(12)*

Commentary

Data acquisition recommendations generally conform to those given for other types of full-scale crash tests in Report 350, FMVSS 214 and SAE J211.(4,13,12) NCHRP Report 350 provides commentary on the use of SAE J211 relevant to instrumentation for roadside hardware crash tests in Chapter 4.*(4,12)*

3.1.1 Vehicle Data

All accelerometers shall be mounted such that the "Y" direction shall correspond to the impact direction in the side impact and the "X" direction shall conform to the forward direction of the vehicle. The "Z" direction shall complete the right-hand-rule suggested by the directions of X and Y. A table listing the accelerometers, their locations, directions and descriptions shall be included in the test documentation. The location shall be documented in coordinates based the distance from the impact side front axle hub.

The test vehicle shall be instrumented with, at a minimum, the following accelerometers as illustrated in Figure 3:

1. Tri-axial accelerometer mounted within a 100-mm diameter sphere centered on the vehicle center of gravity.
2. Uniaxial accelerometer mounted on the non-impact side floor sill in line with the impact point
3. Tri-axial accelerometer mounted on bottom of the driver-side seat under the SID-H3 ATD.
4. Uni-axial accelerometer mounted on the top of the engine.
5. Two uniaxial accelerometers mounted on the impact-side (a) front and (b) rear brake drums or calipers oriented in the impact direction.

Vehicle-mounted accelerometer data shall be collected and processed according to SAE J211 Class 180 rather than Class 1000 as recommended in J211.*(12)*

If an ATD is not used in the test a string pot transducer shall mounted on the inside of the non-impact side door. The string shall be attached to a point on the impact side door in line with the intended impact point. The string pot must be capable of rewinding the string at an acceleration of at least 25 g's. A string pot can also be used when a SID- H3 ATD is used if there is sufficient room to accommodate the string.

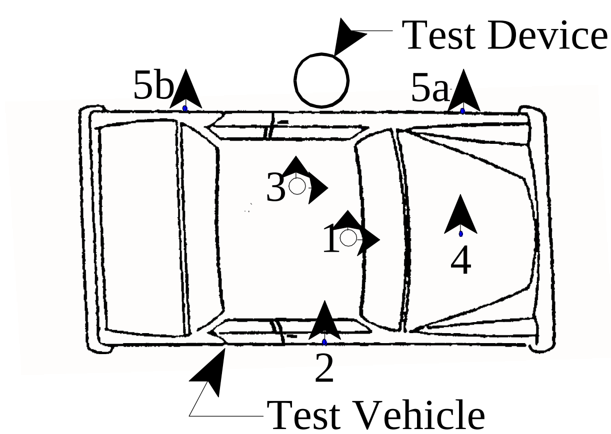

Figure 3. Accelerometers locations.

Commentary

It is necessary to provide enough accelerometers so that the complete six degree of freedom rigid body motion of the vehicle can be determined. The dynamics of side impact collisions are often complex and this data is necessary to completely understand the dynamics of the event. Center of gravity data is collected consistent with the recommendations of NCHRP Report 350.*(4)* While it is not specifically required by Section 3.1.1 it is advisable to use three rate gyros at the center of gravity in addition to the triaxial accelerometers. In principal it is possible to determine the six degree-of-freedom motion of the vehicle from two sets of tri-axial accelerometers placed at a known distance from each other but since there is considerable deformation in side impacts the rigid body assumption is not appropriate and the resulting vehicle kinematics may be erroneous. If possible it is also advisable to use a second tri-axial accelerometer at the center of gravity to provide a level of redundancy to the data collection.

Unlike many roadside safety hardware crash tests the impacted vehicle may be expected to experience extensive deformations even in a successful crash test. Because extensive vehicle deformation is unavoidable it is very important to completely assess the kinematic response of the vehicle.

There have been a considerable number of accelerometer arrangements used in the past for roadside hardware side impacts, FMVSS 214 side impacts and research and development tests. Many of the accelerometers that have been mounted in the impact region on the door or vehicle structure have proven to be of little use since the impact event is of very high intensity and short duration. For example, an accelerometer mounted on the inside of the impact-side door might seem to be a useful location to collect data but in practice it has been found that the resulting time histories are too noisy for any meaningful analysis.

The string pot transducer is used to measure the intrusion and intrusion rate of the door into the passenger compartment. In practice, however, string pot transducers have proven to be fickle and often the intrusion rate is greater than the retraction rate of the string pot for the very early parts of the intrusion event leading to a possible underestimation of the intrusion rate.

3.1.2 Roadside Hardware Test Device

One tri-axial accelerometer shall be attached to the roadside hardware device being tested. The accelerometer shall be attached to the largest mass component of the device nearest the impact point.

Commentary

Selecting the best location for the test device accelerometer will require some intuition and judgement on the part of the test engineer. In principal it is desirable to position the accelerometer as close as possible to the impact location while attaching it to the most massive component available to inhibit noise and accelerometer ringing. Some examples should illustrate the principal. For luminaire support tests an accelerometer should be position on the non-impact face of the pole in-line with the impact at the approximate location of the vehicle center of gravity. For a gating guardrail terminal like the MELT or BCT the accelerometer should be place on the non-impact face of the first breakaway post. It is unlikely that useful data could be obtained if the accelerometer were place on the inside of the nose element of the BCT or MELT where as the post, being larger and more massive may produce more useful data. For guardrail terminals with terminal heads (e.g., the ET-2000, SKT, BEST, FLEAT, etc.) that travel down the rail, the accelerometer should be placed on the top of the head. The intention is to try to collect data on the accelerations and thereby the forces experienced at the front of the struck object.

3.1.3 Anthropometric Test Device

The use of an anthropometric test device (ATD) is optional, as discussed in Section 1.3, though presently highly recommended. If an ATD is used to collect the occupant injury data it shall conform to Part 572 Sub F Side Impact Dummy (SID) with the exception that a Hybrid-III head and neck shall be substituted for the standard SID head and neck. The SID-H3 ATD shall be instrumented such that the head injury criteria (HIC), the thoracic trauma index (TTI) and the maximum pelvis acceleration (P_y) can be calculated as specified in Sections 4.2.1 through 4.2.3. Specific instructions for instrumenting and calibrating the SID are found in the NHTSA Laboratory Procedures for FMVSS 214.*(6)*

All accelerations measured on the SID- H3 ATD shall be collected and processed according to SAE J211 for Class 1000. The SID- H3 ATD data shall be post processed using the FIR100 software incorporated by reference in FMVSS 214.*(13)*

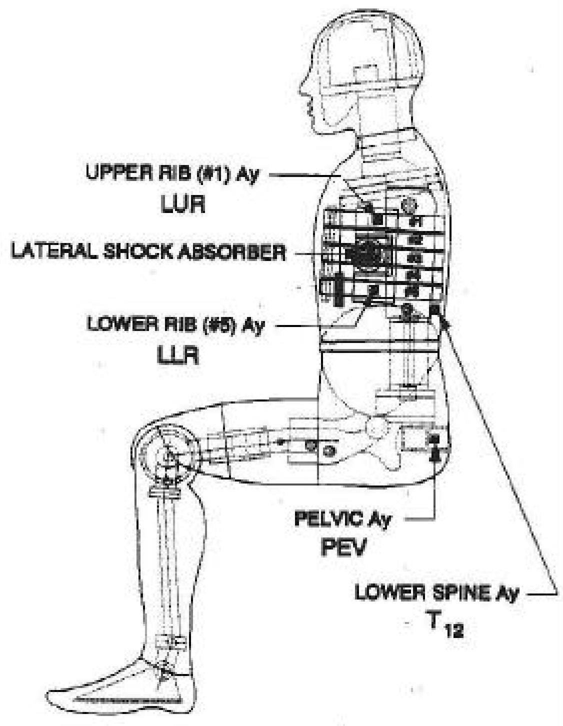

Figure 4 Location of accelerometers on the Part 572 Subpart F Side Impact Anthropometric Test Device.*(6)*

Commentary

The Part 572 Subpart F Side Impact Dummy (SID) is more completely described in the Side Impact Dummy User's Manual included in the FMVSS 214 test procedures.*(6)* The SID is based on the geometry and inertial properties of a 50th percentile male. The head and neck assembly of a Hybrid-III ATD is included since head injury is an important type of injury in side impacts with poles and luminaire supports.

3.2 Photographic Data

The event shall be documented using both still and motion photography. The photography shall be collected in three specific stages: (1) pre-impact, (2) impact and (3) post impact.

3.2.1 Still Photography

Pre- and post-impact photography shall include still prints sufficient to allow someone not present at the test to determine the details of what was tested. Specifically the following still photographs shall be taken before and after the test as a minimum:

- Test placard showing title, impact conditions, date and other basic information,
- Front, rear and sides of the test vehicle,
- Front, rear, sides and oblique angle views of the test device,
- The pre-test vehicle against the test device in the desired impact orientation,
- The post-test vehicle at the point where the vehicle came to rest, and
- Position of the ATD in the front seat.

Commentary
Photographic documentation is one of the most important aspects of the test documentation. The listed photographs are the minimum that are expected and good test documentation will normally require more. Experimenters should attempt to document anything that could possibly be relevant to the analysis of the test. Any short term savings from not taking and processing film is quickly erased if important test details are lost.

3.2.2 Motion Photography
Motion photography may be either 16 mm film or video.

One 24 frames/second real-time documentary view shall be used to record the test placard, the pre-test installation, the real-time impact event and the post-impact damage to both the vehicle and test device. High-speed views shall be in color at 500 frame/second with a timing mark each 10 msec.

Photography during the impact event shall include at least one 24 frames/second real-time view as well as the following 500 frames/second high-speed views:

- One overhead camera at the point of impact,
- Two cameras mounted 90° from each other with both aimed at an oblique angle toward the impact point on the vehicle,
- Two cameras mounted at 90° from each other with the line of sight of one parallel and the other perpendicular to the hypothetical roadway,
- One on-board camera mounted on the passenger-side window frame and aimed at the inside of the impact-side door, and
- (If a SID-H3 ATD is used) One on-board camera mounted parallel to the SID- H3 ATD midsagital plane to document the position of the ATD at impact.

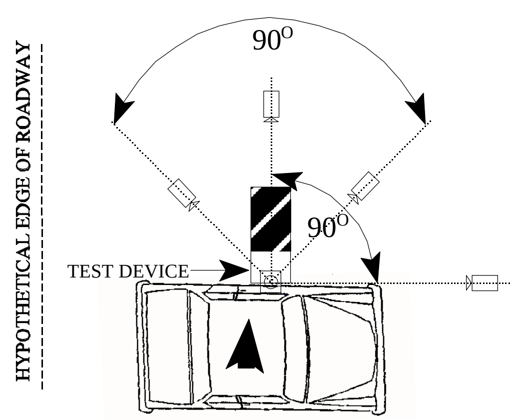

Figure 5. High-Speed Camera Locations.

The locations of all fixed high-speed cameras shall be measured with respect to the impact location and documented in the test report.

An impact switch shall be connected to a high-intensity flash mounted such that it is visible in all high-speed camera views. The switch shall be mounted on the impact face of the door such that the flash will go off at the instant of impact when the force of the impact closes the switch.

Commentary
High speed photographic documentation is one of the most important aspects of full-scale crash tests. Figure 5 shows the locations for the high-speed cameras as described in Section 3.2.2. The cameras that are parallel and perpendicular to the hypothetical traveled way are generally used to collect displacement time data as well as provide a documentary view. The position of the camera must be known and documented for camera views that are to be used to collect displacement-time data. It is considered good technique, however, to record the positions of all cameras.

4 EVALUATION

The side impact collision event shall be evaluated based on (1) the vehicle response (Section 4.1) and (2) the hypothetical occupant response (Section 4.2).

Commentary
The precise techniques for evaluating side impact crash tests have not been finalized but there are several techniques that can be used to evaluate side impact crash tests in the interim. The basic philosophy behind these recommendations is to measure or estimate evaluation parameters consistent with the Federal Motor Vehicle Safety Standard 214 (FMVSS 124).*(13)*

4.1 Vehicle Criteria

4.1.1 Rollover

The vehicle must remain upright throughout the impact event and come to rest on all four wheels.

Commentary
This criterion is similar to Criterion F in NCHRP Report 350.*(4)* Rollover has long been recognized to be an undesirable event in a collision that is frequently associated with increased risk to vehicle occupants

4.1.2 Post-Impact Trajectory

The vehicle must not intrude into an area that would occupy the traveled lanes in an actual field installation. The vehicle should show no tendency for reentering the roadway.

Commentary
This criterion is similar to Criterion K in NCHRP Report 350 but more restrictive since it prohibits intrusion into the traveled way.*(4)* If a vehicle reenters the roadway after the impact it will be a hazard to other traffic and may become involved in an even more serious collision.*(14)*

4.1.3 Emergency Exit
After the test has been performed at least one door of the vehicle must be capable of being opened without the use of any tools.

Commentary
This criterion is adopted from the European side impact test specifications. The objective is to ensure that the occupants of a vehicle are able to escape the vehicle after the collision without being trapped into the damaged vehicle. If the vehicle is a hatch back model the rear door hatch is acceptable as an exit route.

4.1.3 Debris-Free Traveled Way
After the test no debris from either the test vehicle or test article shall show potential for intruding into the traveled way. For evaluation purposes the traveled way shall be considered as the lateral distance between the presumed roadway edge line and the closest distance to the roadway the device would normally be installed.

Commentary
Flying debris from the vehicle of roadside hardware could pose a hazard to other motorists so debris must be contained off the roadway.

4.2 Occupant Criteria
The occupant response may be evaluated using a SID-H3 ATD (Sections 4.2.1 through 4.2.3), approximate occupant response equations (Section 4.2.4 and 4.2.5) or any other method that has a demonstrated link to the TTI, HIC and pelvis acceleration. Regardless of the method chosen, the estimated or actual SID-H3 responses must conform to the following:

- The Head Injury Criteria (HIC) must be less than 1000.
- The Thoracic Trauma Index (TTI) must be less than 90 g's.
- The pelvis acceleration must be less than 130 g's.

A HIC must only be calculated if the struck object extends above the bottom of the driver-side window. A TTI and pelvis acceleration must always be calculated. Correcting for out-of-position SID-H3 ATDs is discussed in Section 4.2.6.

Commentary
The objective of these evaluation criteria are to assess the risk to human occupants of vehicles in side impact collisions. The basis of the evaluation are the widely used HIC, TTI and P_y criteria used in FMVSS 214 and FMVSS 208.*(13) (15)*

At this time the most reliable method of estimating these values is to use an instrumented SID-H3 ATD in the test and measure the values directly. There are several reasons why a testing organization may not want to use an ATD in a side impact test. First, the testing organization may not have access to a SID device or may deem the expense of using one unjustified for preliminary design testing. Second, the test organization may consider the chance of seriously damaging the SID-H3 ATD to be high and may want a lower-cost lower-risk alternative especially for preliminary tests. For these reasons the use of a SID-H3 ATD, while recommended, is not required.

At this time there is no alternative to using an actual SID-H3 ATD in a side impact crash tests. Research is underway to develop injury estimation methods that do not require the use of the SID-H3 ATD but these methods are not as yet available.

4.2.1 Head Impact Criteria

If a SID- H3 ATD is used the head impact criteria shall be calculated using the following expression as defined in FMVSS 208 Section S6.2:*(14)*

$$HIC = \left[\frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a \; dt\right] (t_2 - t_1)$$

where a is the resultant of a triaxial accelerometer mounted at the center of gravity of the SID-H3 head form and t_1 and t_2 are two arbitrary points that are separated by at least 36 msec selected to maximize the value of the HIC. The HIC, as calculated by the above equation, shall be less than 1000. The HIC must be calculated only if the struck object extends above the bottom of the glass driver-side window.

Commentary

The HIC is not, strictly speaking, an appropriate side impact injury measure. It is, however, the only widely accepted measure of head trauma and has a long history of use in frontal crash testing such as FMVSS 208 tests.*(14)* Other researchers have used the HIC to assess lateral head impacts with the upper vehicle interior (e.g., roof rails, upper A pillar, etc.).*(16)*

The conventional limit of 1000 is used although a different tolerance for lateral impacts may be appropriate. There is no experimental biomechanical data at this time, however, to justify a different value for lateral head impacts. Intuition might suggest, however, that if anything the head structure is less resistant to impacts in the lateral direction than in the frontal direction and a lower limit may be appropriate.

A HIC of 1000 is thought to correspond to a probability of AIS>3 head injury of about 0.18.*(17)* The HIC is only required for objects where there is some likelihood that the occupant head could contact the struck object. If the object extends above the bottom of the side windows it should be considered as a potential threat to vehicle occupants. Poles, luminaires and trees are examples of devices where the HIC must be calculated and guardrail terminals are an example where a HIC is generally not required.

4.2.2 Thoracic Trauma Index

The thoracic trauma index (TTI) must be less than 90 g's. The TTI is given by the following expression:

$$TTI = \frac{(G_R + G_{LS})}{2}$$

where G_R is the greater of the left upper rib lateral acceleration (LURY) or the left lower rib lateral acceleration (LLRY). G_{LS} is the maximum acceleration measured at the lower spine (T_{12}).

Commentary
The TTI described by the equation is identical to that used in the NHTSA FMVSS 214 specification.*(13)* The limit of 90 g's is consistent with FMVSS 214 since, as stated in Section 1.2, only two-door models are recommended for roadside hardware tests and 90 g's is the limit specified by FMVSS 214 for two-door passenger cars.*(13)* A TTI of 90 is thought to correspond to a risk of AIS>3 thoracic injury of about 0.16, roughly the same level of risk as represented by a HIC of 1000.*(18)*

4.2.3 Pelvis Acceleration
The maximum pelvis acceleration during the impact event must be less than 130 g's.

Commentary
Pelvis acceleration is expected to generally be of relatively minor importance in most side impact collisions with roadside objects. As discussed above, vehicles generally roll slightly as they move laterally and this tends to promote contact first with the head followed by the thorax and lastly the pelvis. The maximum pelvis acceleration is included primarily for consistency with NHTSA FMVSS 214.*(13)*

4.2.7 Normalizing ATD Position
If SID-H3 ATD is used and it is not located in the typical position the TTI and HIC should be normalized to a standard value. The typical position is defined as the head of the SID-H3 ATD being 250 mm aft of the centerline of the impact and 165 mm from the impact-side door window. The observed TTI can be normalized as follows:

$$TTI_{normalized} = \frac{0.25 \cdot TTI_{observed}}{0.9961^{R}\ 0.9975^{S}}$$

where R is the actual distance in mm from the center of the SID head form to the centerline of the impact in a direction perpendicular to the impact direction and S is the distance from the edge of the head at the ear to the impact side door window.

The observed HIC can also be normalized using the following equation:

$$HIC_{normalized} = \frac{0.21 \cdot HIC_{observed}}{0.9924^R \ 0.9882^S}$$

Commentary
The position of the SID-H3 ATD at the time of impact has a very pronounced affect on the observed HIC and TTI. These equations were developed based on the a multiple linear regression of the results of 11 full-scale crash tests with poles.*(?)* As such they should be viewed as approximate though they are the best approximation currently available.

5 REPORTING AND DOCUMENTATION

The results of a side impact test shall be documented as recommended in Chapter 6 of NCHRP Report 350.*(4)*

6 REFERENCES

1. L. A. Troxel, M. H. Ray and J. F. Carney III, "Side Impact Collisions with Roadside Objects" Roadside Safety Features, Transportation Research Record No. 1302, Transportation Research Board, Washington, D.C., 1991.

2. Ray, M. H., L. A. Troxel and J. F. Carney III, "Characteristics of Side Impact Accidents Involving Fixed Roadside Objects," In Journal of Transportation Engineering, Vol. 117, American Society of Civil Engineers, May-June 1991.

3. Ray, M. H., and J. F. Carney III. "Side Impact Test and Evaluation Procedures for Roadside Structure Crash Tests," Report FHWA-RD-92-062. U.S. Department of Transportation, 1993.

4. H. E. Ross, Jr., D. L. Sicking, R. A. Zimmer and J. D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Features," National Cooperative Highway Research Program Report No. 350, Transportation Research Board, Washington, D.C., 1993.

5. M. H. Ray, M. W. Hargrave, J. F. Carney III and K. Hiranmayee, "Side Impact Test and Evaluation Criteria for Roadside Safety Hardware," In Transportation Research Record, Transportation Research Board, Washington, D.C., 1998 (expected).

6. NHTSA, "Laboratory Test Procedure for FMVSS No. 214: Side Impact Protection -- Passenger Cars," National Highway Traffic Safety Administration, Washington, D.C., 25 May 1992.

7. M. H. Ray, "Impact Conditions in Side Impact Collisions," In *Accident Analysis and Prevention* , Pergamon Press, 1998 (in press).

8. J. Hinch, G. Manhard, D. Stout, R. Owings, "Laboratory Procedures to Determine the Breakaway Behavior of Luminaire Supports in Minisize Vehicle Collisions," FHWA-RD-86-106, Federal Highway Administration, Washington, D.C., February 1987.

9. T. Turbell, “Eftergivliga belysningsstolpar: Utveckling av en provningsmetod och forslag till krav,” Rapport 204, Staten Vag och Trafikinstitut (VTI), Linkoping, Sweden, 1980.

10. C. E. Buth, R. A. Zimmer, and W. L. Menges, “Side Impact Test of the SPSI/ET/Utility Pole,” Report No. 220542-1, Texas Transportation Institute, College Station, TX, 1998.

11. L. A. Troxel, “Characteristics of Side Impact Collisions with Fixed Objects,” M.S. Thesis, Vanderbilt University, Nashville, TN, 1990.

12. SAE J-211, Society of Automobile Engineers, Warrendale, PA, 1988.

13. NHTSA, “Federal Motor Vehicle Safety Standards: Side Impact Protection,” Code of Federal Regulations, 49 CFR 571.214, Washington, D.C., Current through October 14, 1997.

14. M. H. Ray, J. D. Michie, W. W. Hunter and J. Stutts, “An Analysis of the Risk of Occupant Injury in Second Collisions,” Transportation Research Record No. 1133, Transportation Research Board, Washington, D.C., 1987.

15. NHTSA, “Federal Motor Vehicle Safety Standards: Frontal Impact Protection,” Code of Federal Regulations, 49 CFR 571.208, Washington, D.C., Current through October 14, 1997.

16. H. C. Gabler and D. T. Wilke, “Upper Interior Head Impacts: The Safety Performance of Passenger Vehicles,” In *Thirteenth International Technical Conference of Experimental Safety Vehicles*, Vol. 2, National Highway Traffic Safety Administration, Washington, D.C., November, 1989.

17. P. Prasad and H. Mertz, “The Position of the United States Delegation to ISO Working Group 6 on the Use of HIC in the Automotive Environment,” SAE Technical Paper, Society of Automotive Engineers, Warrendale, PA, 1985.

18. R. M. Morgan, J. H. Marcus, and R. H. Eppinger, “Side Impact — The Biofidelity of NHTSA’s Proposed ATD and Efficacy of TTI,” Report No. P-189, Society of Automobile Engineers, Warrendale, PA, October 1986.