Side Impact Crashworthiness Evaluation

Guidelines for Rating Injury Measures (Version II)

April 2008

INSURANCE INSTITUTE FOR HIGHWAY SAFETY

1005 NORTH GLEBE ROAD ARLINGTON, VA 22201
PHONE 703/247-1500 FAX 703/247-1678
http://www.highwaysafety.org

Side Impact Crashworthiness Evaluation
Guidelines for Rating Injury Measures (Version II)

Document Revision History

Version II of the Insurance Institute for Highway Safety *Guidelines for Rating Injury Measures* differs from the original document in the following ways:

> The April 2008 revision of Version II has an added footnote to Table 1 to clarify how and when the peak rib deflection rating criteria is used.
>
> The time interval for evaluating injury measures is now specified; injury measure peaks that occur during dummy inboard rebound are not considered for injury rating.
>
> The rating boundaries for torso deflection rate have been changed to set the good-acceptable boundary at a 5 percent risk of AIS 4+ injury (8.20 m/s); in the previous version 8.20 m/s was the acceptable-marginal boundary for deflection rate.
>
> The torso rating downgrade assessed when shoulder deflection exceeds 60 mm has been extended to include a downgrade for bottoming-out the shoulder. This was necessary due to the observation of shoulder bottoming with deflection levels just below 60 mm.

Injury measures obtained from instrumented 5th percentile female SID-IIs dummies placed in the driver and left rear passenger seats are used to determine the likelihood that occupants in these positions would have sustained significant injury to various body regions. Thirty-seven different measures are recorded by each dummy in the Institute's side impact crash tests:

- head acceleration (three directions from head's center of gravity)
- axial force, anterior-posterior force, lateral-medial force, anterior-posterior bending moment, lateral-medial bending moment, and twist moment acting at the connection between the dummy's head and neck
- spine lateral accelerations measured at T1, T4, and T12
- shoulder lateral deflection, anterior-posterior force, lateral-medial force, and vertical force
- thoracic rib (three) and abdominal rib (two) deflections and accelerations
- pelvic acceleration (three directions)
- pelvic lateral forces measured at the acetabulum and ilium
- distal femur axial force, anterior-posterior force, lateral-medial force, anterior-posterior bending moment, lateral-medial bending moment, and twist moment

The 37 measures are grouped into three body regions: head and neck, torso, and pelvis and left leg. Three injury parameters are calculated for the head and neck, three parameters for each thoracic and abdominal rib in the torso, three parameters for the pelvis, and four parameters for the left leg. The time interval used to rate injury measures for each dummy is limited to the loading phase of the crash and not during dummy inboard rebound. Injury measures throughout the dummy usually peak while the dummy is being loaded by the intruding door structure or side airbag, but in some cases head accelerations and neck forces and moments have peaked during rebound. This is due to dummy kinematics that may not be repeatable (e.g., back of the dummy's head catching the head restraint, which causes the neck to twist as the dummy rebounds inboard, or head contact with the front passenger seat and/or seat back).

Each body region receives an injury protection rating of good, acceptable, marginal, or poor based on the injury parameters for that region. For any body region to receive a good rating, the scores for all injury parameters in that region must indicate good results. If any parameter indicates an acceptable result, then the rating for that body region is acceptable. If any parameter has a marginal result, then the rating for that body region is marginal. Thus the overall injury rating for any body region is the lowest rating scored for an injury parameter within that region.

Table 1 shows the injury parameter ranges associated with the possible ratings: good, acceptable, marginal, and poor. Injury results that round to the values shown in Table 1 will receive the better of the two ratings they separate. It is not possible for an injury-coding scheme to foresee all the possible combinations of outcomes that could suggest injury risk in a crash. Therefore, the information in Table 1 should be interpreted as providing guidelines for evaluating dummy injury measures, which always are subject to modification based on the circumstances of the particular crash test and on new biomechanical information about injury tolerance. Injury assessment reference values (IARVs) are based on current biomechanical information about human injury mechanisms and are described in more detail below.

Table 1
Injury Parameter Cutoff Values Associated with Possible Injury Protection Ratings

Body Region	Parameter	IARV	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Head and neck	HIC-15	779	623	779	935
	Neck axial tension (kN)	2.1	2.1	2.5	2.9
	Neck compression (kN)	2.5	2.5	3.0	3.5
Shoulder	Deflection (mm)*	60			
Torso	Average rib deflection (mm)**	34	34	42	50
	Worst rib deflection (mm)***			Refer to footnote	
	Deflection rate (m/s)	8.20	8.20	9.84	11.48
	Viscous criterion (m/s)	1.00	1.00	1.20	1.40
Pelvis and left femur	Acetabulum force (kN)	4.0	4.0	4.8	5.6
	Ilium force (kN)	4.0	4.0	4.8	5.6
	Combined acetabulum and ilium force (kN)	5.1	5.1	6.1	7.1
	Femur A-P force (3 ms clip, kN)	±3.9	±2.8	±3.4	±3.9
	Femur L-M force (3 ms clip, kN)	±3.9	±2.8	±3.4	±3.9
	Femur A-P bending moment (3 ms clip, Nm)	±356	±254	±305	±356
	Femur L-M bending moment (3 ms clip, Nm)	±356	±254	±305	±356

* If shoulder deflection exceeds 60 mm or bottoms out the torso rating is decreased by one category

** Applies to tests where the maximum rib deflection does not exceed 50 mm.

*** If any of the rib deflections exceed 50 mm, the deflection-based rating will be based on peak deflection. Peak deflections from 51 to 55 mm result in a marginal deflection-based rating for the torso. If any peak deflection is greater than 55 mm, the rating is poor.

Head and Neck

Head injury risk is evaluated mainly on the basis of head injury criterion (HIC) with a 15 ms limit on the period over which it is calculated. A value of 779, which is the maximum allowed in side airbag out-of-position tests with 5th percentile female dummies (Side Airbag Out-of-

Position Injury Technical Working Group, 2000), marks the border between an Institute rating of acceptable and marginal. For an average-sized adult male, a HIC-15 of 700 is estimated to represent a 5 percent risk of a severe injury (Mertz et al., 1997). This value was scaled to give the IARV of 779 for a 5th percentile female. The scaling method used takes into account size and brain tissue strength variation with age (Mertz et al., 1997). A "severe" injury is one with a score of 4+ on the Abbreviated Injury Scale (AIS) (Association for the Advancement of Automotive Medicine, 1990).

Neck injury risk is evaluated on the basis of upper neck axial force, which has been shown to be the best indicator of serious (AIS ≥ 3) neck injury (Mertz et al., 1997; Mertz and Prasad, 2000). Axial forces of 2.1 kN and 2.5 kN mark the borders between Institute ratings of good and acceptable for tension and compression, respectively. These values also are the IARVs for out-of-position testing of side airbags with 5th percentile female dummies and represent about a 3 percent risk of serious neck injury (Mertz et al., 1997).

Torso

The three thoracic and two abdominal ribs of SID-IIs are considered together as the torso. Considering the relatively narrow thorax and abdomen regions of SID-IIs separately may be overly precise given the broad range of occupant statures and possible seating heights. Torso injury risk is evaluated on the basis of thoracic and abdominal deflections, deflection rates, and viscous criterion measures. The overall torso rating is based on the worst rating from these three metrics; however, a downgrade of one rating category is assigned if the shoulder rib bottoms out or its deflection exceeds 60 mm, which is within 1-5 mm of the shoulder rib bottoming-out point. Bottoming-out of the rib typically is identified by a flat-topping in the deflection along with a spike in the shoulder force.

Shoulder: Biomechanical test data suggest that the shoulder complex is capable of transmitting relatively high forces in side impact crashes, but the human tolerance to such loading is not well established; thus shoulder loading is not evaluated separately. However, when the shoulder "rib" of SID-IIs is compressed to approximately 59-65 mm, it contacts a hard stop against the torso where it can transmit artificially high forces into the torso. The purpose for the shoulder-bottoming downgrade is to discourage over-loading the shoulder, which may result in an artificial reduction in loading elsewhere on the torso.

Torso – average deflection: If the maximum thoracic and abdominal rib deflections are less than or equal to 50 mm, the deflection criteria is based on the average of the peak deflections from each rib. An average peak rib deflection less than or equal to 34 mm marks the border between good and acceptable. In the absence of an excessively high single rib deflection, the average rib deflection is used to better correlate with the existing biomechanical test data where large regions of the thorax or abdomen were compressed equally to obtain the human tolerance limits. This deflection also is the single rib IARV used for side airbag out-of-position testing with SID-IIs. The out-of-position reference value was obtained by scaling the BioSID (50th percentile male side impact dummy) IARV of 42 mm (Mertz, 1993). According to injury risk curves that have been scaled for a 5th percentile female, 34 mm of deflection corresponds to a 21-27 percent risk of serious thoracic injuries (Pintar et al., 1997; Viano et al., 1995).

Torso – peak deflection: If any of the five peak rib deflections exceed 50 mm, the deflection-based rating will be evaluated from the peak deflection value instead of the average rib deflection. Although much of the biomechanical tests used to establish human rib deflection tolerance involved distributed loading, Viano (1991) has shown that severe localized deflections are possible with some interior trim designs. When thoracic rib deflection is 50 mm in SID-IIs (about 62 mm in BioSID), there is an 80 percent risk of serious rib fracture injuries; at 55 mm, the risk increases to about 90 percent. Peak deflections from 51 to 55 mm result in a marginal deflection-based rating for the torso. If any peak deflection is greater than 55 mm, the rating is poor.

Deflection rate: A rib deflection rate of 8.20 m/s marks the border between an Institute rating of good and acceptable. This deflection rate IARV is the same as the Hybrid III 5th percentile female sternal deflection rate associated with approximately a 5 percent risk of AIS 4+ thoracic injury in frontal impacts (American Automobile Manufacturers Association, 1998; Mertz et al., 1997). The lateral deflection rate reference value is equal to the frontal deflection rate reference value based on research that has shown similarities in injury severities between thoracic compression rates for frontal and side impacts (Mertz et al., 1982).

Viscous criterion: Another rate-dependent injury criterion, viscous criterion, also is calculated from rib deflection measurements. Viscous criterion is the product of rib deflection, normalized by the chest half-width, and rib deflection rate. According to Viano et al. (1995), a viscous criterion value of 1.0 m/s represents approximately a 5 percent risk of AIS 4+ thoracic injury. A viscous criterion of 1.0 m/s marks the border between an Institute rating of good and acceptable.

Pelvis and Left Leg

Pelvic injury risk is evaluated on the basis of the peak individual forces measured at the acetabulum and ilium and the peak combined instantaneous acetabulum and ilium force. The injury IARV for the acetabulum and ilium are based on the injury research values recommended for pubic symphysis and iliac crest loading in out-of-position testing of side airbags with SID-IIs (Side Airbag Out-of-Position Injury Technical Working Group, 2000). An acetabulum or ilium force of 4.0 kN marks the border between an Institute rating of good and acceptable.

The combined acetabulum and ilium force IARV was determined by rescaling pelvic impact data from Zhu et al. (1993) and Bouquet et al. (1998). In the Bouquet et al. study, pelvic loads were distributed over a wide area (200 × 200 mm square), which included the iliac crest and the greater trochanter. In the Zhu et al. study, the height of the load distribution was considerably lower (102 mm), but the load was measured over an area that covered more than just the greater trochanter. The area over which force was measured in these studies corresponds to a wide pelvic distribution, which is captured closest in SID-IIs by combining the acetabulum and ilium load cell forces. Non-normalized applied force data from these studies were rescaled using the equal stress-equal velocity scaling procedure presented by Eppinger et al. (1984). This procedure also was used by Zhu et al. to scale data to the 50th percentile male standard mass. Logistic probability analysis of each data set showed the risk of AIS 2+ pelvic fracture reached 25 percent at 4.98 kN and 5.27 kN for the Bouquet et al. and Zhu et al. studies, respectively. The instantaneous combined acetabulum and ilium force of 5.1 kN marks the border between an

Institute rating of good and acceptable, which corresponds to an average of the values derived from the Zhu et al. and Bouquet et al. data sets.

Leg injury risk is evaluated on the basis of anterior-posterior force (F_X), lateral-medial force (F_Y), anterior-posterior bending moment (M_Y), and lateral-medial bending moment (M_X) measured at the distal end of the left femur. The femur force and bending moment IARVs are based on the average loads measured in dynamic lateral impacts of femurs from female subjects at the time of fracture initiation (Kerrigan et al., 2003). Although Kerrigan et al. conducted tests only in the lateral-medial direction, the bending tolerance of the femur has been reported to be similar in all directions (Yamada, 1970). Femur forces and bending moments of ±3.9 kN and ±356 Nm, respectively, mark the border between an Institute rating of marginal and poor.

References

American Automobile Manufacturers Association. 1998. Comment to the National Highway Traffic Safety Administration on Advanced Technology Airbags (AAMA S98-13) – Attachment C: Proposal for Dummy Response Limits for FMVSS 208 Compliance Testing. Docket No. NHTSA 98-4405, Notice 1; DMS Document No. NHTSA-1998-4405-79, Dec. 17, 1998. Washington, DC.

Association for the Advancement of Automotive Medicine. 1990. *The Abbreviated Injury Scale, 1990 Revision*. Des Plaines, IL.

Bouquet, R.; Ramet, M.; Bermond, F.; Caire, Y.; Talantikite, Y.; Robin, S.; and Voiglio, E. 1998. Pelvis human response to lateral impact. *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles*. Washington, DC: National Highway Traffic Safety Administration.

Eppinger, R.H.; Marcus, J.H.; and Morgan M.M. 1984. Development of dummy and injury index for NHTSA's Thoracic Side Impact Protection Research Program. SAE Technical Paper Series 840885. Warrendale, PA: Society of Automotive Engineers.

Kerrigan, J.R., Bhalla, K.S., Madeley, N.J., Funk, J.R., Bose, D., Crandall, J.R. 2003. Experiments for Establishing Pedestrian-Impact Lower Limb Injury Criteria. SAE Technical Paper Series 2003-01-0895. Warrendale, PA: Society of Automotive Engineers.

Mertz, H.J. 1993. Anthropomorphic test devices. *Accidental Injury: Biomechanics and Prevention* (eds. A.M. Nahum and J.W. Melvin), 66-84. New York, NY: Springer-Verlag.

Mertz, H.J. and Prasad, P. 2000. Improved neck injury risk curves for tension and extension moment measurements of crash test dummies (SAE 2000-01-SC05). *Stapp Car Crash Journal* 44:59-76. Warrendale, PA: Society of Automotive Engineers.

Mertz, H.J.; Prasad, P.; and Irwin, N.L. 1997. Injury risk curves for children and adults in frontal and rear collisions (SAE 973318). *Proceedings of the 41st Stapp Car Crash Conference* (P-315), 13-30. Warrendale, PA: Society of Automotive Engineers.

Mertz, H.J. and Weber, D.A. 1982. Interpretations of the impact responses of a three-year-old child dummy relative to child injury potential. *Proceedings of the 9th International Technical Conference on Experimental Safety Vehicles*, 368-76. Washington, DC: National Highway Traffic Safety Administration. (Also published as SAE Technical Paper Series 826048)

Pintar, F.A., Yoganandan, N., Hines, M.H., Maltese, M.R., McFadden, J., Saul, R., Eppinger, R., Khaewpong, N., Kleinberger, M. 1997. Chestband analysis of human tolerance to side impact (SAE 973320). *Proceedings of the 41st Stapp Car Crash Conference* (P-315), 63-74. Warrendale, PA: Society of Automotive Engineers.

Side Airbag Out-of-Position Injury Technical Working Group (A joint project of AAM, AIAM, AORC, and IIHS) (2000) Recommended procedures for evaluating occupant injury risk from deploying side airbags. August 8, 2000.

Viano, D.C. 1991. Evaluation of armrest loading in side impacts (SAE 912899). *Proceedings 35th Stapp Car Crash Conference*, 145-62. Warrendale, PA: Society of Automotive Engineers.

Viano, D.C.; Fan, A.; Ueno, K.; Walilko, T.; Cavanaugh, J.; and King, A. 1995. Biofidelity and Injury Assessment in EuroSID I and Biosid (SAE 952731). *Proceedings of the 39th Stapp Car Crash Conference*, 307-25. Warrendale, PA: Society of Automotive Engineers.

Yamada, H. 1970. *Strength of Biological Materials*. Baltimore, MD: The Williams and Wilkings Company.

Zhu, J.Y.; Cavanaugh, J.M.; and King, A.I. 1993. Pelvic biomechanical response and padding benefits in side impact based on a cadaveric test series (SAE 933128). *Proceedings of the 37th Stapp Car Crash Conference*, 223-33. Warrendale, PA: Society of Automotive Engineers.