Moderate Overlap Crashworthiness Evaluation 2.0 Rating Guidelines

Version III

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CONTENTS

DOCUMENT REVISION HISTORY

Revisions to Version III

An automated script is now used to calculate the dynamic belt position. For more information, see *Appendix A: Calculating the Dynamic Belt Position*.

OVERVIEW

This document provides the rating guidelines for the Insurance Institute for Highway Safety (IIHS) moderate overlap 2.0 crash test (Jagtap et al., 2023).

The front-seat occupant is a Hybrid III 50th Percentile Male (H350M) anthropomorphic test device (ATD).

The rear-seat occupant is a Hybrid III 5th Percentile Female ATD (H35F).

Injury ratings for each occupant are dictated by the worst metric in each body region with downgrades, where applicable. The restraints and kinematics rating for each occupant are dictated by the sum of the accumulated demerits.

DRIVER

Injury rating (driver)

Injury measures obtained from an instrumented H350M in the driver seat are used to determine the likelihood that an occupant would have sustained significant injury to various body regions. Thirty-two different measures are recorded in each moderate overlap crash test:

- Head acceleration and angular rate (three directions from the head’s center of gravity)
- Axial force, anterior-posterior force, lateral-medial force, and anterior-posterior bending moment acting at the connection between the dummy’s head and neck
- Thoracic spine acceleration (three directions)
- Sternum compression
- Femur axial force (each leg)
- Tibia-femur displacement (each leg)
- Tibia transverse bending moments (upper and lower, each leg)
- Tibia axial force (each leg)
- Foot acceleration (two directions, each foot)

The 32 measures are grouped into four body regions: head and neck, chest, thigh and hip, and legs and feet. Four injury parameters are used to evaluate protection for the head and neck, three parameters for the chest, one for each thigh and hip, and five parameters for each leg and foot.

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 (worst) rating scored for an injury parameter within that region. The thigh/hip and leg/foot ratings are based on the lowest rating scored from either the left or right limb.

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. With some exceptions (e.g., chest acceleration), the borders between acceptable and marginal ratings for a given injury parameter correspond to published injury assessment reference values (IARV) for significant injury related to that parameter. Acceptable ratings correspond to measures somewhat below (better than) the IARVs, and good ratings correspond to measures well below the IARVs. Similarly, marginal ratings correspond to measures just above (worse than) the IARVs, and poor ratings correspond to measures well above the IARVs.

Information about the origin and associated injury risks for each of the injury measures in the head/neck, chest, and leg/foot regions are described in the *Moderate Overlap Frontal Crashworthiness Evaluation Guidelines for Rating Injury Measures* (IIHS, 2014). Additional injury criteria for the head and thigh/hip regions are described below.

Table 1
Injury reference values and rating boundaries for the H350M driver dummy

Body region	Parameter	IARV [a]	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Head and neck	HIC-15	700	560	700	840
	Nij	1.00	0.80	1.00	1.20
	Neck axial tension (kN)	3.3	2.6	3.3	4.0
	Neck compression (kN)	4.0	3.2	4.0	4.8
Chest	Thoracic spine acceleration (3-ms clip, g)	60	60	75	90
	Sternum deflection (mm)	−50	−50	−60	−75
	Sternum deflection rate (m/s)	−8.2	−6.6	−8.2	−9.8
	Viscous criterion (m/s)	1.0	0.8	1.0	1.2
Thigh and hip	Knee-thigh-hip injury risk		5%	15%	25%
Leg and foot	Tibia-femur displacement (mm)	−15	−12	−15	−18
	Tibia index (upper, lower)	1.00	0.80	1.00	1.20
	Tibia axial force (kN)	−8.0	−4.0	−6.0	−8.0
	Foot acceleration (g)	150	150	200	260

Note. HIC = head injury criterion. IARV = injury assessment reference values.

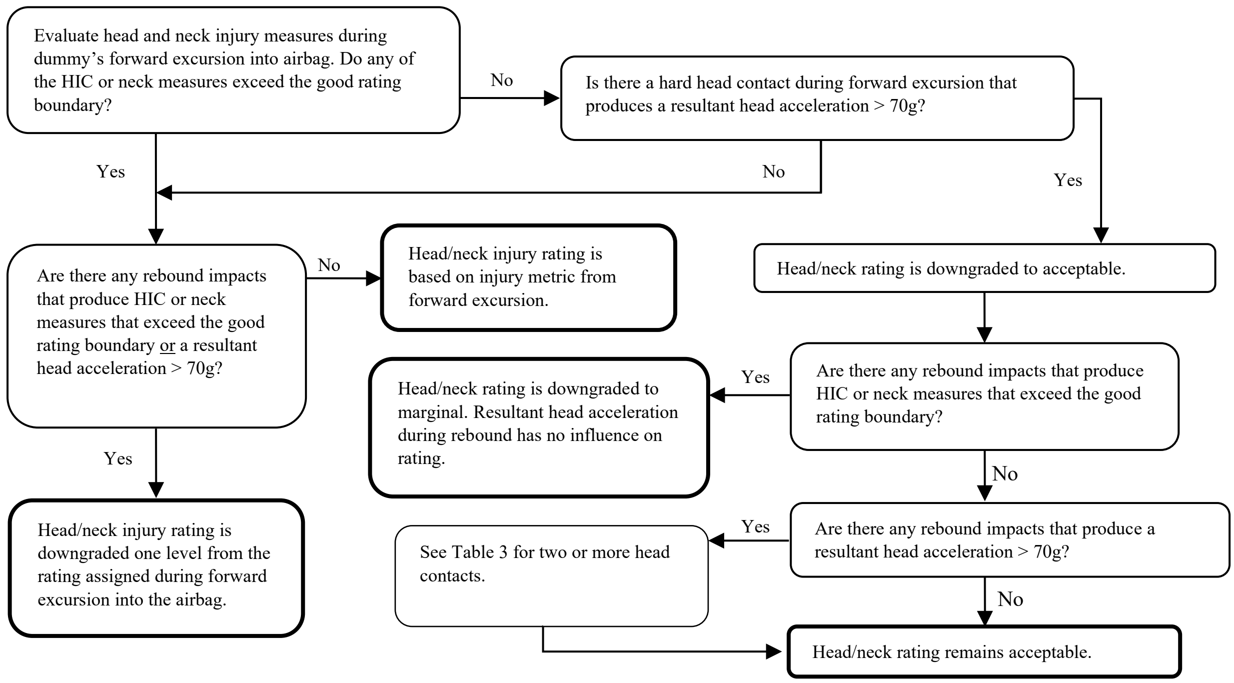
[a] See IIHS's *Moderate Overlap Frontal Crashworthiness Evaluation: Guidelines for Rating Injury Measures* (September 2014).

Head and neck (driver)

Head injury risk is evaluated mainly on head injury criterion (HIC) calculated over a 15-ms period. A value of 700, which is the maximum allowed under the provisions of the U.S. advanced airbag rule (National Highway Traffic Safety Administration [NHTSA[, 2000), marks the border between a rating of acceptable and marginal.

In addition to HIC-15, the maximum vector resultant acceleration of the head is considered. A maximum head acceleration that exceeds 70 g and is caused by contact between the head and a hard surface of the vehicle interior can result in lowering the head injury rating one level (details are provided in Figure 1).

Figure 1
Flowchart: Influence of rebound impacts on the driver head/neck injury rating



Note. HIC = head injury criterion.

A head/neck rating that is otherwise good will be lowered to acceptable if the neck tension, compression, or shear (X direction) forces fall outside the force duration corridors specified by Mertz (1984). The force duration corridor limits are shown in Appendix C.

Neck injury risk is evaluated primarily based on N_{ij}, neck tension force, and neck compression force. The N_{ij} is a linear combination of neck axial force (F_Z) and the bending moment about a lateral axis passing through the dummy's occipital condyle (M_Y), as shown in Equation 1. The critical values against which the force and moment are compared depend on the direction of the applied loads, as shown in Table 2 (Eppinger et al., 2000). An N_{ij} value of 1.0 marks the border between a rating of acceptable and marginal.

$$N_{ij} = (F_Z / F_{critical}) + (M_Y / M_{critical}) \quad (1)$$

Table 2
Critical values for H350M N_{ij} calculation

	Tension ($+F_Z$) / Flexion ($+M_Y$)	Compression ($–F_Z$) / Extension ($–M_Y$)
Neck axial force (F_Z)	6806	6160
Front/back bending moment (M_Y)	310	135

In addition to N_{ij}, neck axial force by itself is compared with the cutoff values shown in Table 1. Axial forces of 4.0 and 3.3 kN mark the borders between ratings of acceptable and marginal for compression and tension, respectively.

Chest (driver)

Chest injury risk is evaluated based on sternum deflection, sternum deflection rate, viscous criterion, and thoracic spine acceleration.

A sternum deflection of 60 mm marks the border between a rating of acceptable and marginal. This is near the same limit used to evaluate compliance with the U.S. advanced airbag rule (NHTSA, 2000).

A sternum deflection rate of 8.2 m/s marks the border between a rating of acceptable and marginal.

Another rate-dependent injury criterion, viscous criterion, also is calculated from sternum deflection measurements. Viscous criterion is the product of sternum deflection, normalized by chest depth, and the sternum deflection rate. A thoracic spine acceleration of 60 g (3 ms) marks the border between a rating of good and acceptable. This value also is used to evaluate compliance with the U.S. advanced airbag rule (NHTSA, 2000).

Thigh and hip (driver)

Thigh and hip injury risk is evaluated based on the knee-thigh-hip (KTH) injury criteria developed by Rupp et al. (2009). The KTH criteria uses a combination of peak compressive force and impulse recorded at each femur to determine the risk of an AIS 2+ knee/distal femur fracture and AIS 3+ hip fracture. A relatively low level of risk of KTH injury is required to obtain a good thigh/hip injury rating because of the greater threat to life and long-term disability associated with fractures to the thigh (due to proximity of femoral artery) and hip.

The KTH impulse is calculated by integrating the femur force from the start of femur compression (the time that force last equals zero prior to the peak compressive force) to the time after the peak force when compressive force last falls below 4,050 N (Figure C4). A KTH injury risk of 5% marks the border between an IIHS rating of good and acceptable. The force impulse corridor limits are shown in Figure C5.

Legs and feet (driver)

Leg and foot injury risk is evaluated based on femur axial force, tibia-knee displacement, tibia indices measured at the upper and lower portions of the tibia, tibia axial force measured at the distal end of the tibia, and foot acceleration.

A tibia-femur displacement of 15 mm marks the border between a rating of acceptable and marginal. This is the reference value recommended by Mertz (1984) and based on work by Viano et al. (1978). Similarly, a tibia index of 1.0 is the cutoff value between an acceptable and marginal rating. Tibia indices are calculated using adjusted bending moments as shown in Equations 2 and 3 to account for the fact that the shape of the Hybrid III dummy's legs causes unhumanlike bending under the influence of pure axial forces. The details of the rationale for this adjustment are described by Zuby et al. (2001) and Welbourne and Schewchenko (1998).

$$M_{Y\ upper\ adj} = M_{Y\ upper\ meas} - [(F_{Z\ tib})(0.02832)]\text{, moment in Nm, force in N} \quad (2)$$

$$M_{Y\ lower\ adj} = M_{Y\ lower\ meas} + [(F_{Z\ tib})(0.006398)]\text{, moment in Nm, force in N} \quad (3)$$

The acceptable-marginal cutoff value for tibia axial force is somewhat lower than the reference value recommended by Mertz (1984) because Crandall et al. (1998) have shown that heel fractures (AIS 2, but associated with a high degree of impairment) occur at considerably lower forces.

Zeidler (1984) suggested the conservative limit of 150 g for foot acceleration based on tests with volunteers and dummies. This level of acceleration is associated with jumps from a height beyond which injury was feared. Consequently, it marks the limit allowed for a good rating, whereas only much higher accelerations result in marginal or poor leg/foot ratings.

Restraints and kinematics (driver)

The injury measures obtained from a H350M seated in a standard driver's position are good indicators of the injury risk for a person of about the same size in the same seating position. However, good injury results for the standard dummy and seating position are not sufficient by themselves to indicate low injury risk for drivers of different sizes and/or seating positions in the same crash. For example, the dummy's head moving outside the occupant compartment and/or the steering column moving excessively during the crash indicate the potential for injuries that are not necessarily captured by recorded injury measures on a single dummy.

To provide some assessment of the potential injury risk for drivers of other sizes and/or seating positions, IIHS reviews the kinematics (high-speed video analysis) of the dummy during the moderate overlap frontal crash, together with the performance of the restraint system (seat belts, airbags, steering column, seat, and door). The restraints and dummy kinematics rating system is based on demerits, with every vehicle beginning with a good rating. The test is intended to determine if there are reasons to lower the rating. Details of the demerit scheme are described in Table 3.

The basic characteristics of good occupant restraint/dummy kinematics performance are:

- the dummy should move straight forward into a fully deployed airbag and then return directly to the seat during rebound;
- the head and body should stay behind and within the extended perimeter of the airbag;
- the head should not approach hard surfaces of the vehicle interior;
- rearward and upward movement of the steering column should be minimal; and
- lap belts should have stable anchorages that allow only minimal lengthening or spool-out even when force-limiting devices are used.

Table 3
Restraint and kinematic downgrades for the H350M driver

Restraint and kinematic events	Demerits
Side curtain airbag not equipped or did not deploy	1
Movement of *most* of the dummy's head through the original plane of the vehicle's side window	3
Two or more distinct head contacts with stiff structures that each generate more than 70 g of maximum acceleration (e.g., contacts with the steering wheel *and* B-pillar)	4
Instability of the seat due to floorpan or seat-riser deformation	3
Excessive rearward, lateral, or upward movement (≥ 100 mm) of the steering column	3
Moderately excessive (100–150 mm), uncontrolled lengthening of the lap belt	3
Burning or melting of dummy body parts or clothing due to the expulsion of hot gases from deflating airbags during impact	3
Dummy movement considerably less controlled (e.g., the head and shoulders pass through the original plane of the side window, or there is sufficient rotation of the upper torso for the head to face upward or nearly upward on rebound from the airbag), regardless of contact with a stiff structure	7
Vehicle door opening	10
Failure of seat attachments	10
Excessive belt slack introduced by belt tearing	10
Frontal airbag deployed late or did not deploy	10

	Good	Acceptable	Marginal	Poor
Total restraint and kinematic demerits	0–1	2–5	6–9	≥ 10

REAR OCCUPANT

Injury rating (rear occupant)

Injury measures obtained from a H35F and associated instruments in the second-row left seating position are used to determine the likelihood that an occupant would have sustained significant injury to the head, neck, chest and thighs. The following measurements are collected for rating from the dummy and associated instruments in/on the second-row left passenger seat.

- Head acceleration (three directions from the head's center of gravity)
- Axial force and anterior-posterior bending moment acting at the connection between the dummy's head and neck
- Sternum compression
- Left and right iliac forces and moments
- Femur axial force (each leg)
- Shoulder and lap belt tension force
- Position of shoulder belt on thorax

Peak injury values for the rear occupant are collected and reported for the entire event, unless they exceed a rating boundary. Values that exceed rating boundaries are only reported and rated if they occur during the primary loading (forward excursion) phase of the event. 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 (worst) rating scored for an injury parameter within that region. The thigh rating is based on the lowest rating scored from either the left or right leg. More details on the research supporting rating decisions for the rear occupant can be found in the publication: *Development of rear-seat occupant safety metrics for the moderate overlap frontal evaluation test* (Edwards et al., 2023).

Table 4 shows the injury parameter ranges associated with the possible ratings: good, acceptable, marginal, and poor. Some parameters have only one value that differentiates pass/fail status or a downgrade. Injury results that round to the values shown in Table 4 will receive the better of the two ratings they separate.

Table 4
Injury reference values and rating boundaries for the H35F rear occupant

Body region	Parameter	IARV	Good – Acceptable	Acceptable – Marginal	Marginal – Poor
Head and neck	HIC-15 [a] (only used with contacts)	779	560	700	840
	Nij [b] (only used with contacts)	1.00	0.80	1.00	1.20
	Neck axial tension [a] (kN)	2.6	2.0	2.4	2.8
	Neck compression [a] (kN)	2.5	2.0	2.5	3.0
	Head resultant acceleration from contact (g)	—	Head and neck rating is downgraded one level over 70 g		
Chest			**Good – Acceptable**	**Acceptable – Marginal**	**Marginal – Poor**
	Chest Index [c]	—	35	40	45
	Shoulder belt tension (kN)	—	Good ≤ 5.9 < Marginal		
			Good – Acceptable	**Acceptable – Marginal**	**Marginal – Poor**
Thigh	Femur axial compression [a] (kN)	6.2	4.9	6.2	7.4

Note. HIC = head injury criterion. IARV = injury assessment reference values.

[a] Based on Mertz et al., 2016.

[b] Based on Eppinger et al., 2000.

[c] For more information, see *Calculating the Chest Index* on the following pages.

Head and neck (rear occupant)

When a contact occurs with the vehicle interior, head injury risk is evaluated using the head injury criterion (HIC) and the maximum resultant values. HIC is calculated over a 15-ms period and a resulting value of 700 marks the border between a rating of acceptable and marginal. A maximum resultant head acceleration that exceeds 70 g when caused by contact between the head and a hard surface of the vehicle interior results in lowering the head and neck injury rating one level.

Neck injury risk is evaluated primarily using neck tension and compression values, taking into consideration N_{ij} values only when occupant motion is complicated by impacts with the vehicle interior. The N_{ij} critical values against which the force and moment are compared are occupant-size specific; the values for the H35F dummy are shown in Table 5 (Eppinger et al., 2000). An N_{ij} value of 1.0 marks the border between a rating of acceptable and marginal.

Table 5
Critical Values for H35F N_{ij} Calculation

	Tension ($+F_Z$) / Flexion ($+M_Y$)	Compression ($-F_Z$) / Extension ($-M_Y$)
Neck axial force (F_Z)	4287	3880
Front/back bending moment (M_Y)	155	67

With or without vehicle interior contacts, neck axial force by itself is compared with the cutoff values shown in Table 4. Axial forces of 2.5 and 2.4 kN mark the borders between ratings of acceptable and marginal for compression and tension, respectively.

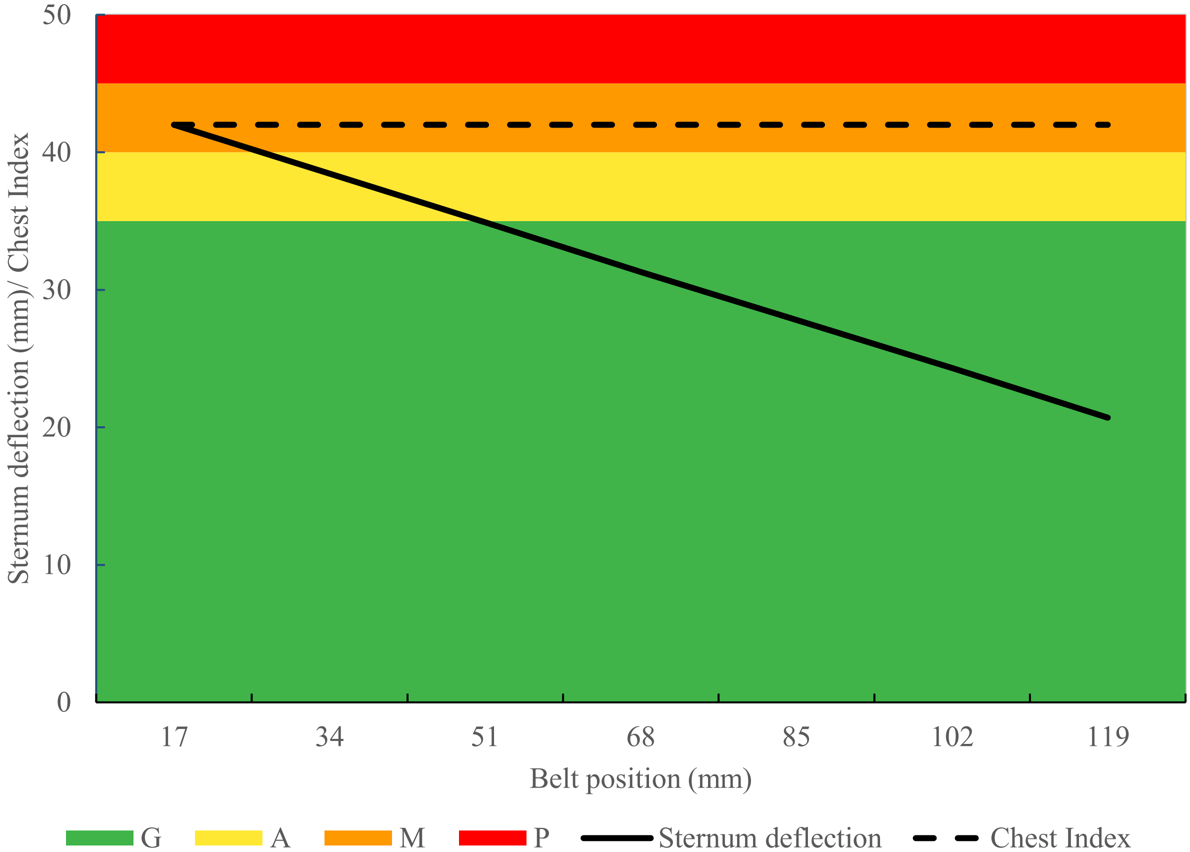
Chest (rear occupant)

Chest injury risk is evaluated using Chest Index and the shoulder belt tension peak.

Chest Index was developed with the aim of providing a metric for comparing vehicle chest protection without the influence of the belt position on sternum deflection. Edwards et. al (2022) studied the sensitivity of the H35F sternum deflection measurement to belt position in the rear-seat environment and found a linear relationship of a 0.5% reduction in sternum deflection per millimeter of increase in vertical belt distance, relative to a point 25 mm above the sternum potentiometer. Chest Index (calculated by Equations 4 and 5) uses this sensitivity and the dynamic belt position (relative to the chest potentiometer) measured during the test to adjust the sternum deflection to a metric that reflects what would be expected for the tested vehicle at a standard belt position, 17 mm above the sternum potentiometer (Table 6). This point approximately corresponds to the midpoint of the third rib (rib 3) and also has a correction factor that rounds to 0.5%.

Chest Index is meant to provide a fair comparison between restraint systems regardless of the belt position on the chest (Figure 2), but because it is a departure from the sternum deflection output of the sensor, it does not relate to injury risk curves that have been established for the H35F dummy sternum deflection.

Figure 2
Sample data illustrating how sternum deflection decreases with increased belt position, but Chest Index remains constant



Calculating the Chest Index

Table 6
Chest Index calculation matrix

Dynamic belt position [a]	**Chest Index calculation method**
≤ 17 mm	Chest Index [b] = $\lvert$Sternum deflection$\rvert$
> 17 mm	Chest Index [b] calculation

[a] For a definition, see Table 7.

[b] Chest Index is rounded down to the nearest whole number before the rating is applied.

Chest Index calculation

$$Predicted\ percent\ change\ in\ sternum\ deflection\ (Pchange) = \frac{(0.5/100)}{1\ mm} \times (dynamic\ belt\ position - 17\ mm) \quad (4)$$

$$Chest\ Index = \frac{|Measured\ sternum\ deflection|}{\left(1 - (Pchange)\right)} \quad (5)$$

Table 7
Constants and definitions

Term	Definition
$\frac{(0.5/100)}{1\ mm}$	Reduction in sternum deflection per 1-mm increase in belt position from a baseline position of 17 mm from the sternum potentiometer
17 mm	Position of rib 3 relative to the sternum pot ball on the rear occupant's uncompressed thorax.
Dynamic belt position (mm) [a]	Vertical distance from the sternum pot ball on the rear occupant's uncompressed thorax to the centerline of the shoulder belt at the time of maximum sternum deflection (see Appendix A).
Measured sternum deflection (mm)	Maximum value measured by the sternum potentiometer on the rear occupant. (The calculation uses two decimal places; e.g., 25.64.)

[a] Details on the procedure for measuring belt position using a high-frequency pressure sensor can be found in Appendix A.

Though shoulder belt tension is not measured on the dummy itself, it has been shown to be correlated with thorax injuries in real-world crashes (Foret-Bruno et al., 1998; Kahane, 2013). A shoulder belt tension peak value of 5.9 kN is the IIHS maximum allowable value to pass this requirement. For most vehicles tested in the IIHS moderate overlap crash configuration, restraining an occupant the size of the H35F dummy results in shoulder belt tensions above this value, unless pretensioner and/or force limiting technology is present in the belt.

Thigh (rear occupant)

Though the H35F dummy represents the stature of the majority of rear-seat occupants, its stature may be a shortcoming when trying to represent the risk of femur injuries. However, it is important to monitor femur axial force because it is a potential load path for occupant restraint. A femur axial compression value of 6.2 kN marks the border between a rating of acceptable and marginal.

Restraints and kinematics (rear occupant)

The injury measures obtained from a H35F seated in a standard second-row seating position are good indicators of the injury risk for a person of about the same size in the same seating position. However, the alignment of crash test results with real-world outcomes is affected by using one stature of dummy to represent the broad range of occupants in the rear seat and by the limitations of using an ATD as a human surrogate. Adding restraints and kinematics ratings that include head excursion limits to prevent head impacts and observations of the belt movement off the pelvis (i.e., submarining) and shoulder help address the known dummy shortcomings in order to provide a reliable vehicle assessment.

IIHS reviews the kinematics of the dummy during the moderate overlap frontal crash using high-speed video analysis, together with the performance of the restraint system (seat belts, airbags, seat, and door). The restraints and dummy kinematics rating system is based on demerits, with every vehicle beginning with a good rating. The test is intended to determine if there are reasons to lower the rating. Details of the demerit scheme are described in Table 8.

The basic characteristics of good occupant restraint/kinematics performance in the rear seat are as follows:

- a large buffer of space should be maintained between the ATD's head and the driver seatback to account for occupants of larger stature;
- the ATD's head should not approach hard surfaces of the vehicle interior;
- the lap belt should remain on both sides of the ATD's pelvis during forward excursion;
- the shoulder belt should remain on the thorax and shoulder during forward excursion;
- on rebound, the ATD's head should move back without moving outside the side curtain airbag or side window and without hard contacts with the vehicle interior; and
- the seat and restraint attachments should remain stable.

Head excursion (rear occupant)

Head excursion is measured relative to the pretest position of the rearmost point on the front seatback. Vertical tape lines are marked on the interior of the door with the forward edge aligned with the longitudinal position of the rearmost point on the front seatback and 50 mm rearward of the pre-impact seatback line (Figure 3a). At the time of the maximum forward excursion of the head, a judgement is made using video on how far the head has moved relative to these lines (Figure 3b). Demerits are applied for only one of the following categories: behind the 50-mm line, between the 50-mm line and the seatback line, beyond the seatback line, or contact with the front seatback.

An attempt is made to always align the camera for this judgement with the 50-mm line. However, in cases where this cannot be achieved, the parallax error affecting the view is taken into consideration as shown in Appendix B.

Figure 3
Head excursion

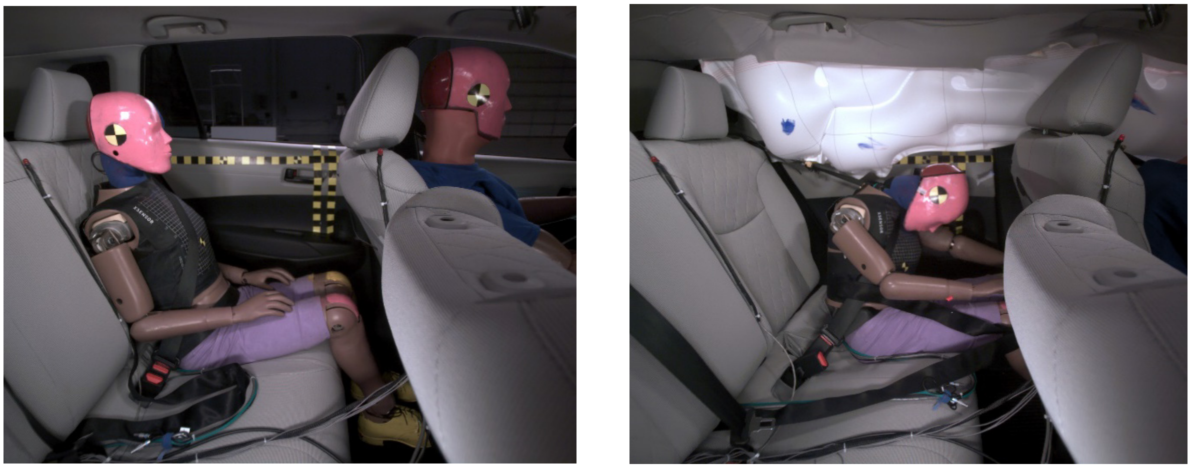


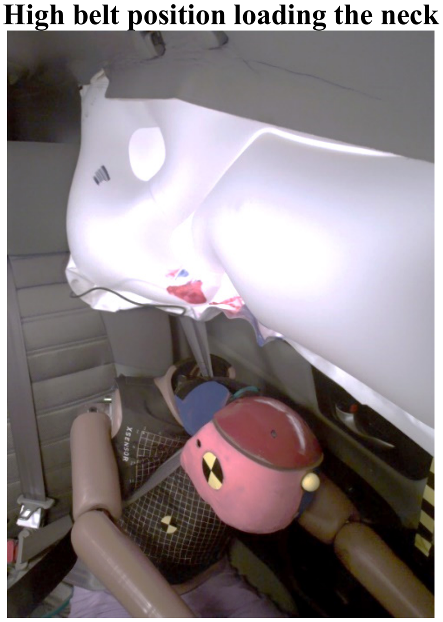
Figure 3a. Lines are marked on the interior of the door at the rearmost point of the front seatback and 50 mm behind that line.

Figure 3b. At maximum forward excursion, a judgment on how far the head has moved is made using these lines

Maximum dynamic belt position (rear occupant)

Seat belt position on the occupant is an important factor for proper seat belt use and effective occupant restraint. Belt position is measured using a high-frequency pressure-mat sensor at both the time of maximum sternum deflection to be used in the Chest Index calculation and at the time of maximum movement away from chest potentiometer (i.e., upward toward the neck) (see Appendix A). IIHS has observed that most belt positions higher than 120 mm from the chest potentiometer compromise the effectiveness of the restraint system because the shoulder belt is actually loading the neck (Figure 4) instead of the thorax.

Figure 4
High belt position loading the neck



Submarining (rear occupant)

Submarining of the seat belt occurs when the lap belt is not sufficiently engaged with the pelvis, allowing the body to move down and forward relative to the belt, which can result in direct loading of the abdomen through the lap belt. The H35F does not have sensors to directly assess the risk of injury from belt loading to the abdomen, so the increased risk is assessed by observing whether submarining is present.

Submarining is evaluated primarily by video analysis of the lap belt position. Figure 5 shows examples of lap belt position scenarios. Figure 5a shows a stable belt position. Submarining demerits are applied if the belt moves off the pelvis on either one or both sides (Figures 5b and 5c). If camera views are obstructed, submarining is confirmed by superimposing the iliac loads over the lap belt load to observe whether the curves deviate from each other (Figure 6).

Figure 5
Video examples of submarining

Figure 5a. Stable belt position

Figure 5b. Belt migration over the right ASIS

Figure 5c. Belt migration over both the left and right ASIS

Figure 6
Iliac and lap belt load cells submarining/no submarining examples

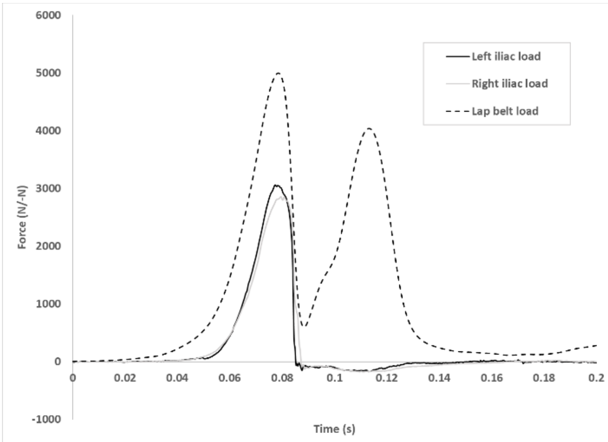


Figure 6a. H35F iliac and lap belt loads when submarining occurs

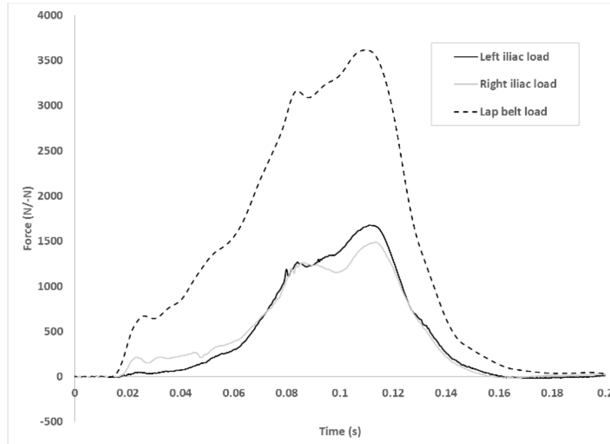


Figure 6b. H35F iliac and lap belt loads when submarining **does not** occur

Table 8
Restraint and kinematic downgrades for the H35F rear occupant

Restraint and kinematic events	Demerits
Head excursion (only one applies) [a]	
50-mm line	2
Front-seatback line at test position	4
Head contact	9
Maximum dynamic belt position [b] > 120 mm	4
Submarining	6
Rebound head-contact resultant acceleration (3 ms) > 70g	2
Lack of head containment during rebound or unsafe deployment [c] (only one of the following applies)	
Head is outside of the side curtain airbag, curtain airbag is not equipped or did not deploy, or an unsafe deployment occurred	2
At least half of the head is outside the window plane	6
Instability of the seat due to floorpan or seat-riser deformation	3
Occupant burn risk	3
Vehicle door opening	10
Failure of seat attachments	10

	Good	Acceptable	Marginal	Poor
Total restraint and kinematic demerits	0–1	2–5	6–9	≥ 10

[a] See Appendix B for details on head-excursion measurements.

[b] Belt position is measured at the highest position on the chest. See Appendix A for details on calculating the dynamic belt position.

[c] An example of an unsafe deployment scenario is a loading head-contact resultant acceleration > 70g with a side curtain airbag.

STRUCTURE

Overview

Injury measures recorded on the ATDs are used as one indicator of crashworthiness performance. These measures are not the only indicators, however, because although high injury measures recorded in the test mean some people in similar real-world crashes would sustain significant injuries, the converse is not true. Low injury measures do not necessarily mean there is no risk of significant injury to people in similar crashes. This is because the forces experienced by people of different sizes from the ATD, or seated in different positions, can be quite different, especially when there is significant collapse of/intrusion into the occupant compartment. Major deformation or intrusion into the compartment is a good predictor of injury risk for people in similar crashes, even when ATD injury measures are low. For this reason, the structural integrity of the occupant compartment, or safety cage, is evaluated and is used as an important additional indicator of crashworthiness performance. Specific measurements of intrusion into the occupant compartment are used to assess this aspect of performance.

Measurements of safety cage deformation

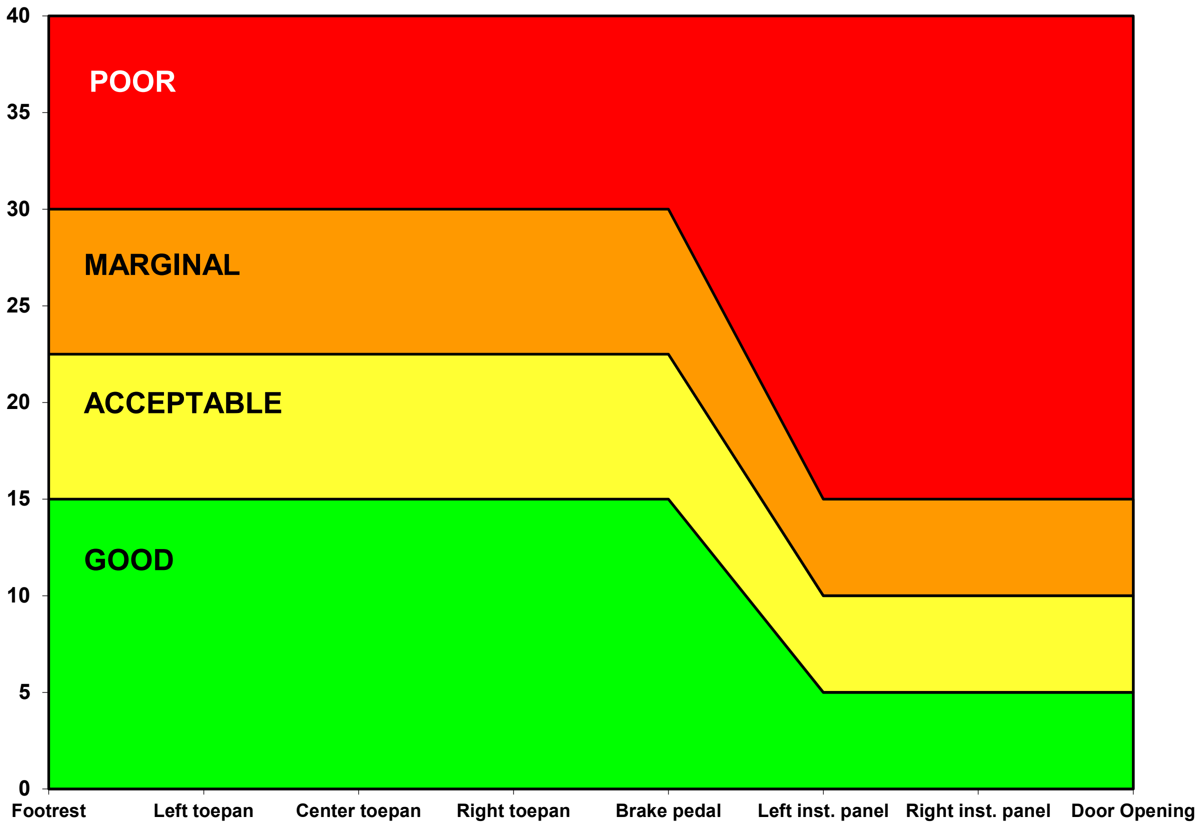
The measurements used to rate structure represent the residual movement (precrash/postcrash difference) of interior structures in front of the driver dummy. The movement of seven points on the vehicle interior plus the closing of the distance between the A- and B-pillars are the foundations of the structural rating. Two of the interior measured points are located on the lower instrument panel, in front of the dummy's knees; four points are in the footwell area, three across the toepan and one on the driver's outboard footrest; the last measured point is on the brake pedal. The precrash and postcrash locations of these points are measured with respect to a coordinate system originating on the driver door striker. The measured movement of the interior seven points is adjusted to reflect movement toward the driver seat, which is represented by the locations of its attachment to the vehicle floor. Thus, movement of the driver seat with respect to the reference coordinate system is not reflected in evaluations of vehicle structure (this adjustment is not made for the A-to-B-pillar closure). A further adjustment may be made to the brake pedal intrusion in the event of pedals that "break away" or otherwise deform to limit intrusion. If a brake pedal is constructed so that it dangles loosely after the crash, the brake pedal is pushed straight forward against the toepan and held there to take the postcrash measurement. If the pedal drops away entirely, no postcrash measurement is taken.

Evaluating intrusion measurements

The initial structural rating is based on comparison of intrusion measurements with rating guidelines (Figure 7). This rating may then be modified (downgraded) on the basis of additional observations about the structural integrity of the safety cage.

The X-Y-Z vector resultant movements of the toepan, footrest, and brake pedal points are used for comparison with the rating guidelines. If the X movement is forward (away from the driver seat), then only the Y-Z vector resultant movement is used. Only the rearward movement (X) of the instrument panel is compared with the guidelines. Figure 7 shows the ranges for these measurements and associated structural ratings. Vehicle models with all intrusion measures falling in the area labeled good will receive a good structural rating if no additional observations lead to a downgraded rating. Similarly, vehicle models with all intrusion measures falling into one of the other three zones shown in Figure 7 will receive an acceptable, marginal, or poor rating unless there are modifying observations.

Figure 7
Guidelines for rating occupant compartment intrusion (cm)



When intrusion measurements fall in different rating bands, the final rating generally reflects the band with the most measures. However, the final rating typically will not be more than one rating level better than the worst measurement. For example, a vehicle with a poor measurement for the left instrument panel would not score better than marginal for structure, even if all other measured values were good. Where there are ties, with half the measurements in one band and half in another, the final rating typically will be that of the worst band. Intrusion measurements falling on a boundary value will be considered to fall in the band that represents the better rating.

Qualitative observations leading to downgraded structure rating

Some patterns of deformation are less desirable regardless of intrusion measurements. For example, a footwell that collapses in a way that traps the dummy's feet represents a greater injury risk than a footwell with similar intrusion measurements that does not trap the dummy's feet. Another example of a potentially modifying observation involves intrusion into the safety cage of some component or structure not captured by the ten measurement points (e.g., complete tearing of hinge pillar). If a modifying observation is made, then the overall structural rating will be lowered one level from the rating suggested by the intrusion measurements (e.g., from acceptable to marginal).

If more than one test is conducted of the same make and model with no structural changes in the same model year or consecutive model years, the structure rating will be based on the average measurements from the multiple tests except in the cases of one or more intrusion measurements spanning two or more rating bands. In such cases, the combined structure rating will be based on the worst case. For example, if a vehicle had a marginal toepan measure and a second example of the same vehicle had a good measure at the same point, this could be an indicator of lack of stability or robustness in the vehicle design. In such a case, the average rating of the toepan would be marginal, not acceptable, which in turn could affect the final structure rating.

Fuel and high-voltage system integrity leading to downgraded rating

If a significant fuel leak or compromise of a high-voltage system (i.e., electric drivetrain) is observed during a test, both the structural and overall ratings may be downgraded to poor. Significant fuel leaks are those that exceed the leak rate allowed following tests conducted to assess fuel system integrity under U.S. Federal Motor Vehicle Safety Standard (FMVSS) No. 301 (2017).

Additionally, smoke and fire events in low-voltage circuits (cut and shorted wires, crushed electrical components, etc.) are investigated postcrash and, depending on findings, may result in downgrades.

High-voltage systems must meet the electrolyte spillage, battery retention, and electrical isolation requirements in FMVSS 305 (2019) to avoid downgrade. Additionally, the temperature of the high-voltage battery will be monitored both with a thermocouple and a thermal imaging camera, before and after a crash test. If an increase in temperature is detected, the vehicle will be moved immediately outdoors where continued monitoring will take place. The following summarizes these requirements:

Electrolyte spillage

No more than 5 liters of electrolyte from propulsion batteries shall spill outside the passenger compartment and no visible trace of electrolyte shall spill into the passenger compartment.

Electric energy storage/conversion system retention

Electric energy storage/conversion devices mounted outside the occupant compartment shall remain attached to the vehicle by at least one component anchorage, bracket, or any structure that transfers loads from the device to the vehicle structure and shall not enter the occupant compartment.

Electrical isolation

After the test, one of the following requirements must be met:

- Electrical isolation between the high-voltage source and vehicle chassis must be greater than or equal to 500 ohms/volt for all high-voltage sources without continuous monitoring of electrical isolation. The isolation must be greater than or equal to 100 ohms/volt for all DC high-voltage sources with continuous monitoring of electrical isolation; or

- The voltages from high-voltage sources measured according to the procedure specified in FMVSS 305 (2019) must be less than or equal to 30 VAC for AC components, or 60 VDC for DC components.

Temperature increase

While postcrash activities commence, the battery temperature will be monitored with the onboard thermocouple for at least 4 hours. An increase in temperature from ambient laboratory temperature (20–22.2 degrees Celsius) will trigger an onboard temperature alarm at 25.5 degrees Celsius, resulting in the immediate evacuation of the vehicle from the facility. If over the next 2 hours of monitoring, both with the thermocouple and thermal imaging camera, the temperature begins to stabilize, and there are no visible signs of fire (i.e., smoke), postcrash activities can continue. A measured temperature above 25.5 degrees Celsius, or visible smoke or fire, will result in a poor overall vehicle rating.

WEIGHTING PRINCIPLES FOR OVERALL RATINGS

Table 9
Weighting principles for vehicle structure and dummy measures (driver and rear passenger)

	Good	Acceptable	Marginal	Poor
Vehicle structure				
Structure and safety cage	0	4	10	20
Driver dummy				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Leg and foot	0	1	4	6
Restraints and kinematics	0	1	4	6
Rear-passenger dummy				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh	0	2	6	10
Restraints and kinematics	0	2	10	15
Total score	**0–5**	**6–10**	**11–24**	**> 24**

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APPENDIX A: CALCULATING THE DYNAMIC BELT POSITION

The belt pressure impression from the pressure sensor is combined with the pretest data from a coordinate measurement machine (CMM) to locate the dynamic belt position on the rear-passenger dummy's thorax.

The dynamic belt position is defined as the vertical distance from the chest potentiometer to the belt centerline. All CMM measurements are recorded in the dummy-thorax coordinate system (IIHS, 2025; Appendix) established before the crash test. All belt position measurements are rounded down to the nearest whole number.

IIHS determines the dynamic belt position using an automated script. When necessary, a manual calculation method is available (for more information, see *Manual calculation method* on page 29).

IIHS automated script

The IIHS script completes the following steps to calculate the dynamic belt position.

1. Imports and prepares the data

   The pressure sensor data frames are imported and aligned with the corresponding baseline CMM coordinates. The chest potentiometer location and sternum deflection data from the test are imported.

2. Cleans the data

   Corrupted frames are identified using frame-to-frame pressure deviation thresholds and are removed to prevent discontinuities in the pressure signal. High-frequency speckle noise is detected using differential and ratio-based criteria, and identified speckle values are replaced using neighborhood averaging to ensure valid, stable pressure distributions.

3. Detects the belt centerline

   a. Identifies the left and right belt-edge points

      For each frame, the pressure data is evaluated using a defined pressure threshold to identify cells that represent belt contact. The left and right belt-edge points are identified, ensuring that only physically connected belt-contact regions are retained.

   b. Refines the belt-edge points

      Edge points are first screened using a row-column ratio criteria to remove points that do not conform to the expected belt geometry. The remaining points are subject to random subsampling to estimate slope and intercept values for left and right belt edges.

      The script excludes points deviating beyond allowable distance limits from the median fit. Using the remaining points, the script identifies a final left and right belt-edge line.

   c. Calculates the belt centerline

      The final left and right belt-edge lines are averaged to produce the belt centerline for each frame.

4. Calculates the dynamic belt position

   For each frame, the vertical distance between the belt centerline and the chest potentiometer is computed to get the raw dynamic belt position.

5. Interpolates and filters

   The signal for the raw dynamic belt position is interpolated to a uniform 10-kHz sampling rate to match the sternum deflection data channel. This interpolated signal is then filtered using channel frequency class 60 (SAE International, 2014) and merged with the sternum deflection channel to compute the Chest Index and other evaluation metrics.

If you have any questions about the automated script or would like to request access, please contact Sushant Jagtap at sjagtap@iihs.org.

Manual calculation method

In instances where the pressure sensor data exhibits quality issues that result in inaccurate calculations by the automated script, the following manual calculation method can be used.

Dynamic belt position is calculated at two instances: at maximum sternum deflection and at the maximum dynamic belt position. The belt position at maximum sternum deflection reflects the dynamic belt position approximately at the time of the maximum compression recorded by the chest potentiometer. The maximum dynamic belt position refers to the highest belt position on the dummy's thorax during the loading phase prior to rebound, when a belt impression can be seen in the pressure sensor data. In some cases, these two positions can be identical. Three independent dynamic belt position calculations are performed, and the lowest result of the three are used for ratings.

The procedure for calculating belt positions is similar for both instances and is as follows:

1. The output file from the pressure sensor is checked for any loss of data, errors, etc. The appropriate frame for consideration is identified in the pressure sensor software (XSensor HSI software or equivalent) (Figure A1).
2. For each sensel (individual 5×5-mm pressure sensor element) that registers pressure, the corresponding Z-axis location (Figure A2) is obtained from the pretest CMM data.

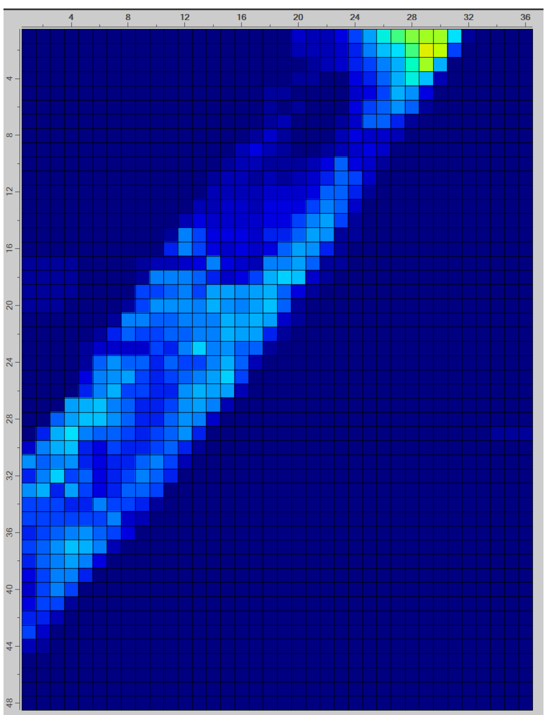

Figure A1. Belt pressure impression output from pressure mat at the frame in consideration

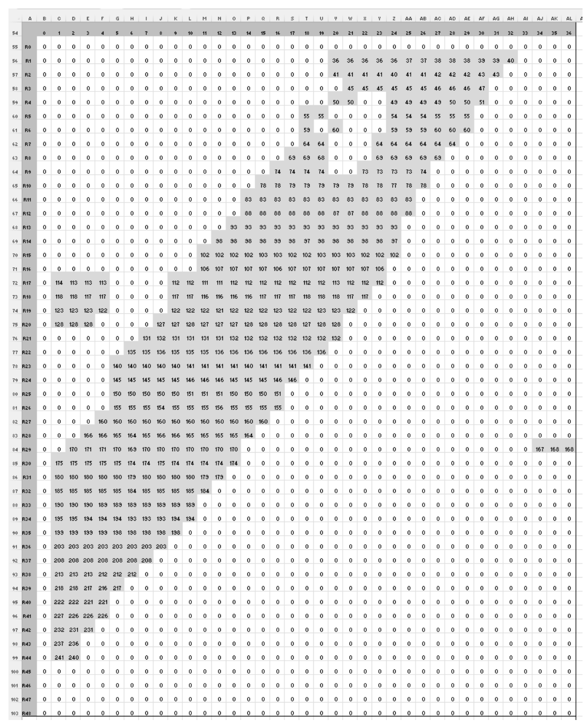

Figure A2. Corresponding Z-axis location of each sensel registering pressure (highlighted in grey)

3. The belt path is calculated by identifying the center of the belt impression for each column at this frame. The following guidelines are used to accurately calculate belt path:
   - In columns where the midpoint of the belt is being calculated, pressure registered by contacts other than belt loading (Figures A3, A5) is removed by either increasing the pressure threshold (in the HSI software, Figure A4) or by manually editing the respective sensel values to zero (Figure A6). If the external contacts cannot be distinguished from the belt path in the identified frame, the nearest time frame where the external contacts can be distinguished is considered.

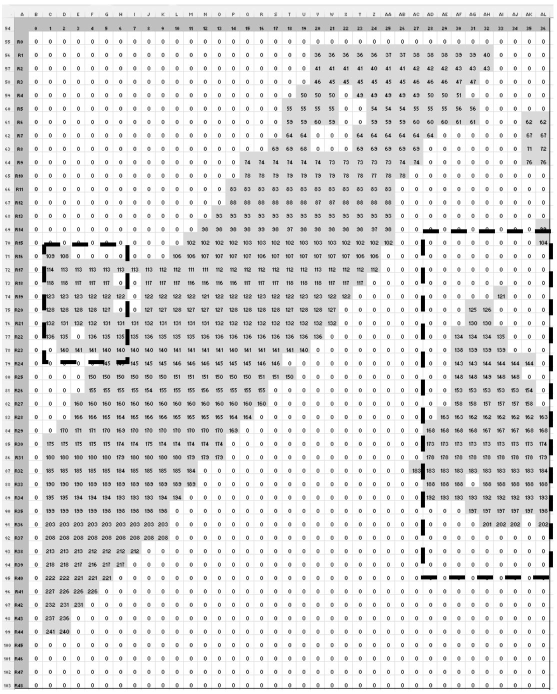

Figure A3. Pressure registered by contacts other than belt loading

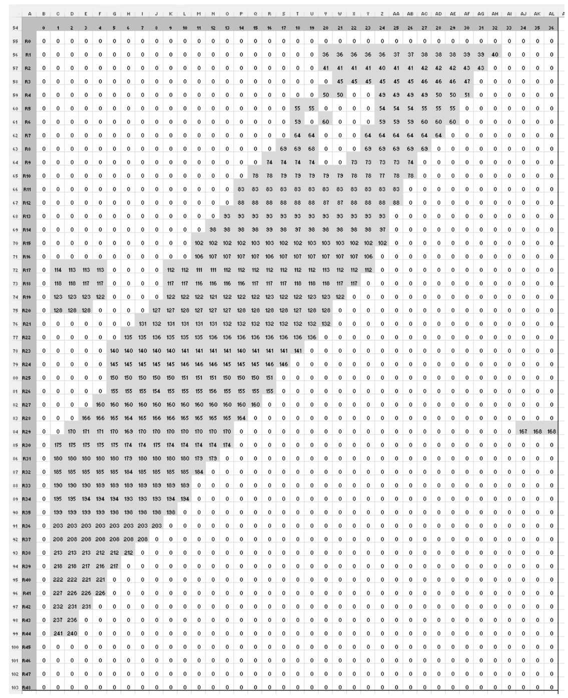

Figure A4. Increasing the pressure threshold to remove pressure registered by other contacts

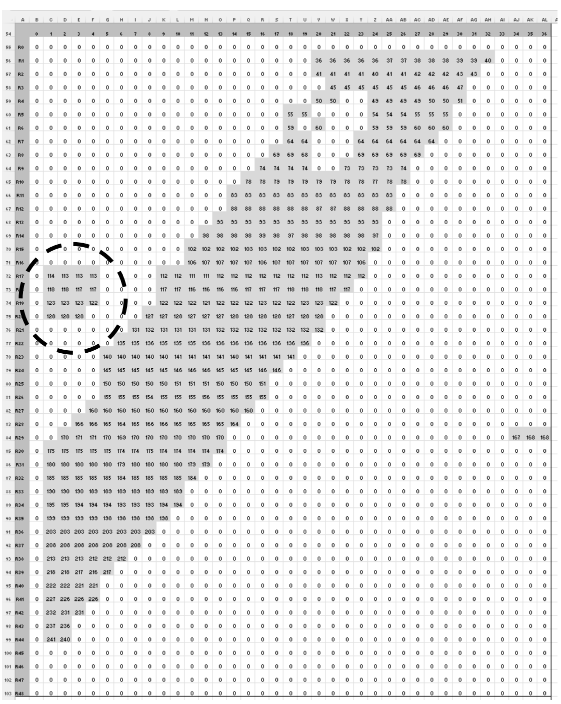

Figure A5. Pressure registered by sensels other than belt loading

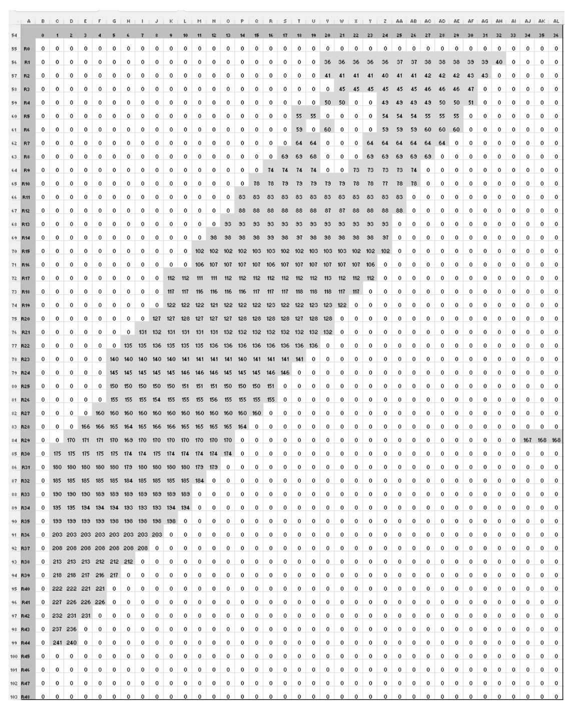

Figure A6. Manually removing the pressure registered by sensels

- In some cases, there can be sensels along the belt path that register zero pressure (Figure A7). These sensels are manually edited to calculate the accurate belt path (Figure A8).

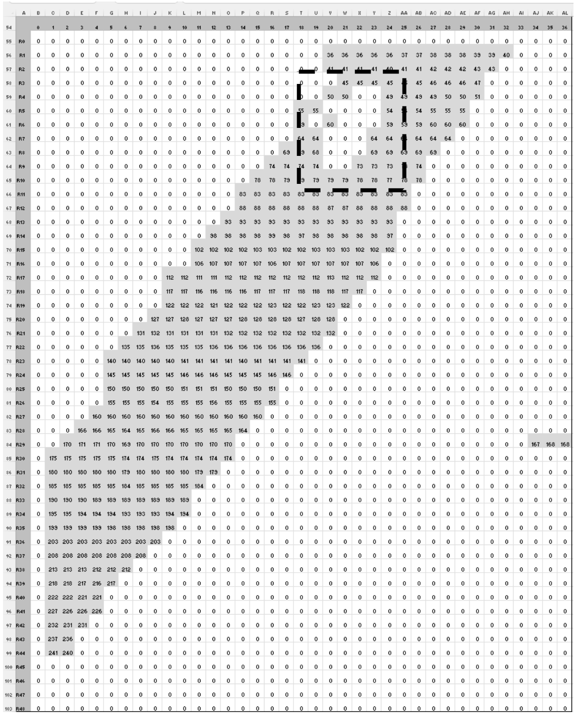

Figure A7. Sensels along the belt path that register zero pressure

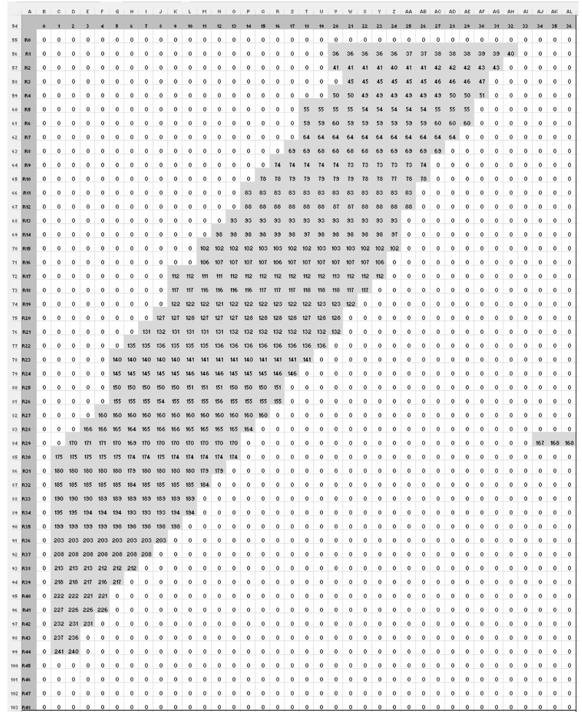

Figure A8. Manually editing sensels to calculate the accurate belt path

- To avoid errors in calculation, the belt path center is calculated only in the columns where the complete width of the belt is visible (Figure A9).

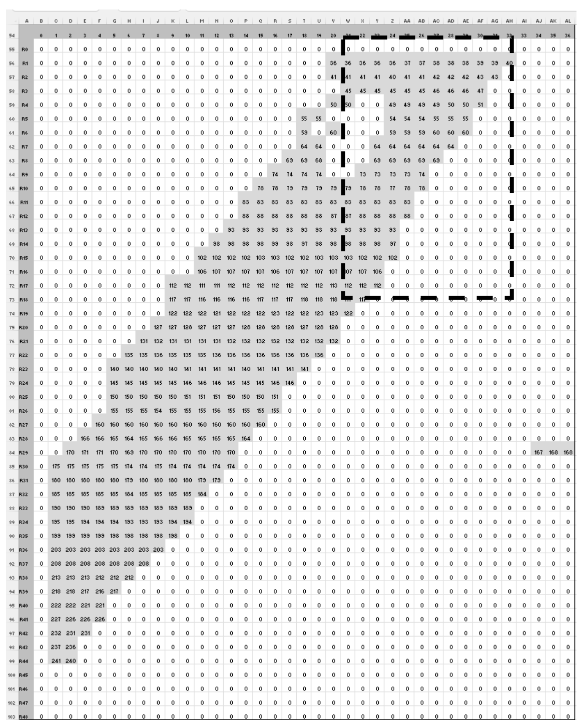

Figure A9. Belt path center is not calculated in highlighted columns because of missing top edge of belt

- The center of each column is calculated to identify the centerline of the dynamic belt path (Figure A10).

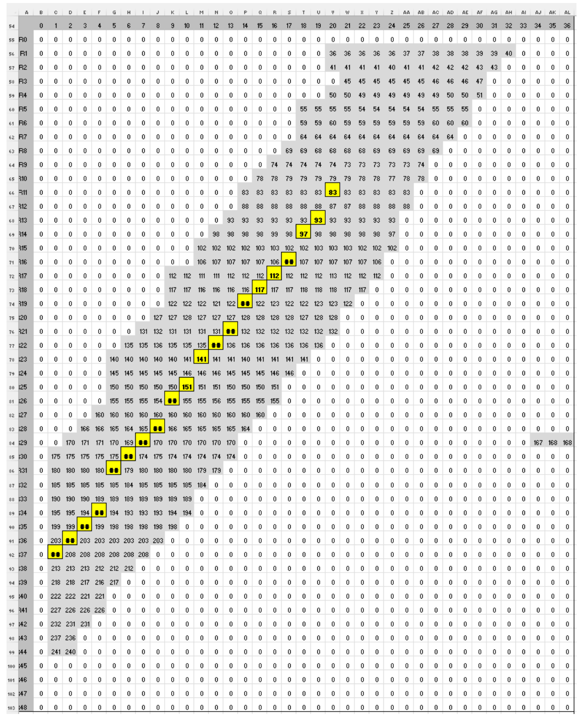

Figure A10. The centerline of the dynamic belt path (indicated by the highlighted [yellow] sensels)

4. A regression equation is created by using the belt path points identified in step 3. This regression equation is then used to calculate the dynamic belt position by interpolation.

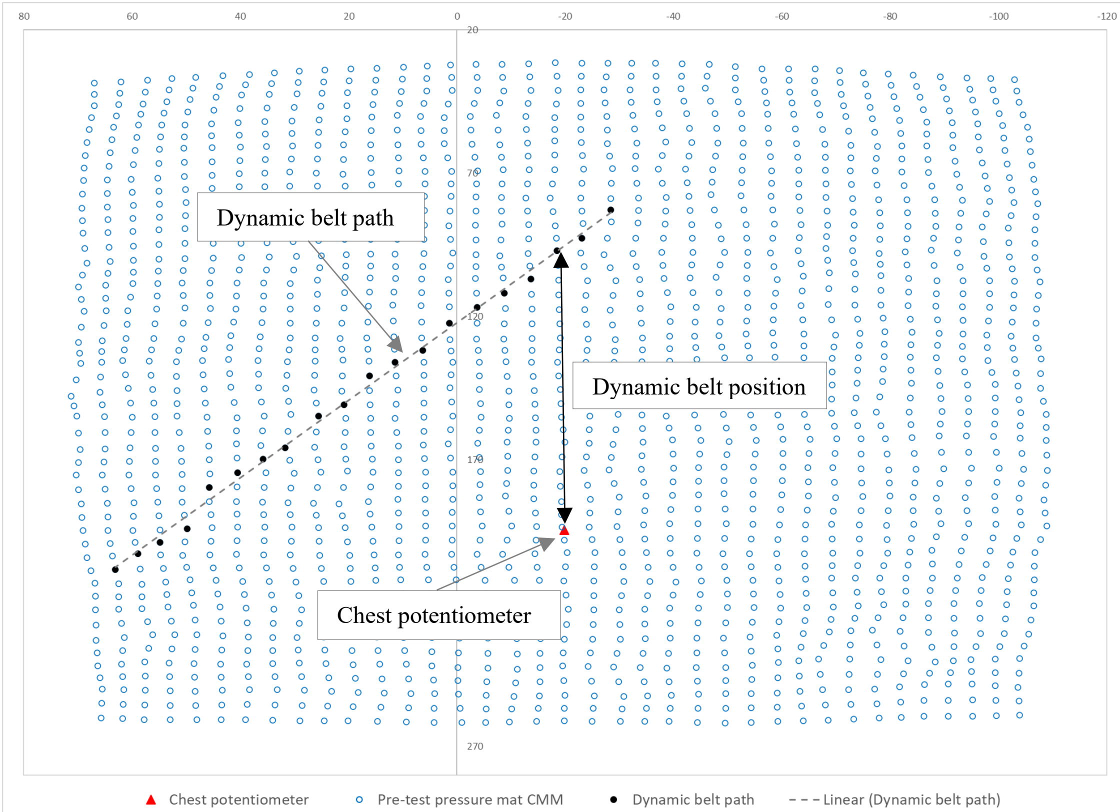

Figure A11. Calculating the dynamic belt position

References (Appendix A)

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APPENDIX B: CALCULATING THE CAMERA PARALLAX ERROR

The leading edge of two vertical excursion lines placed on the interior rear left door and on the camera located at the rear-passenger door (camera K, Figure B2) are used for judging head excursion (Figure B1).

Camera K is aligned 50 ± 5 mm longitudinally behind the front-seatback line. In this standard position, any camera parallax error would be approximately constant between tests and is not considered when judging head excursion. In cases where it is not possible to align camera K 50 ± 5 mm behind the seatback line, the camera parallax error is calculated using the formula below and the guidelines in Table B1 are followed while judging head excursion.

Figure B1
Vertical excursion lines used for judging head excursion

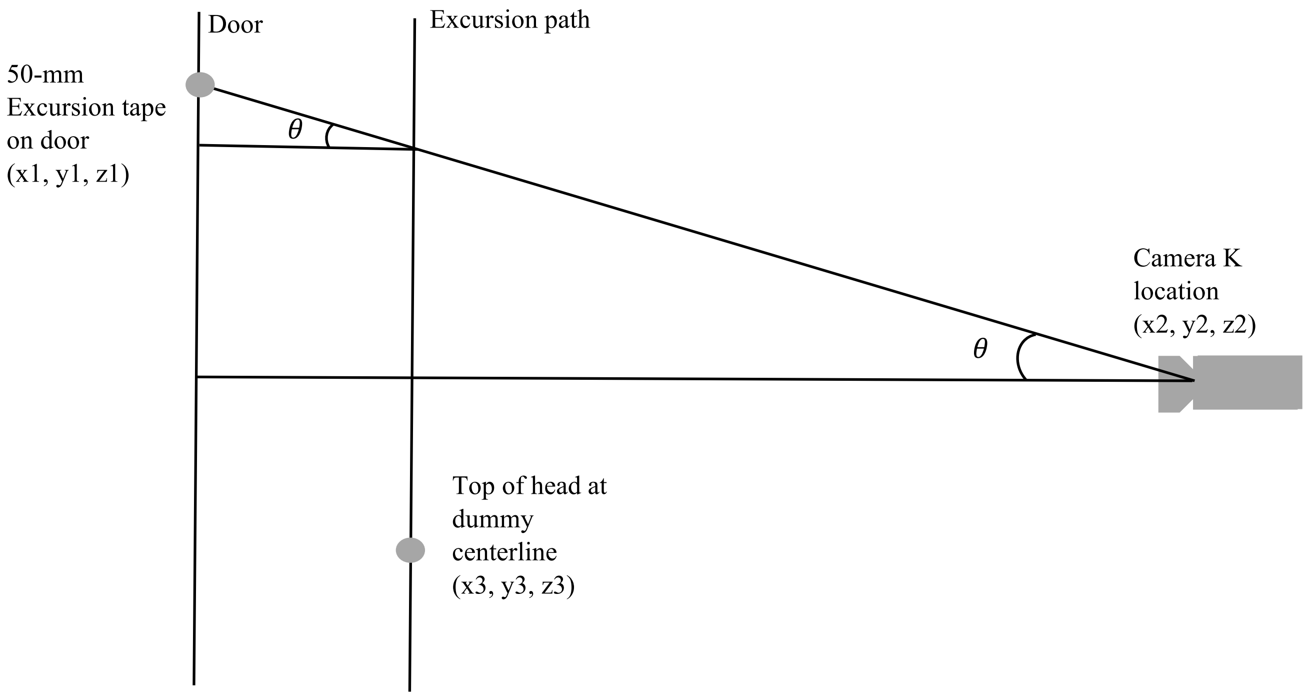
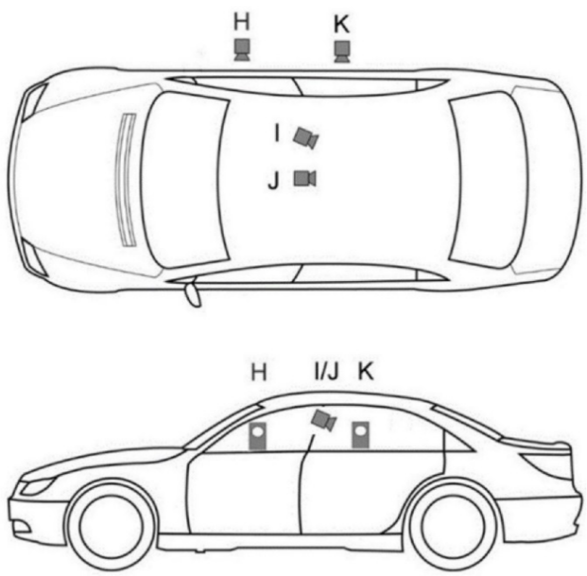


Figure B2
Onboard high-speed camera positions



Formula for calculating the parallax error

$$Error = (y_3 - y_1) \times tan\,\theta$$

$$where\ \theta = tan^{-1}\left(\frac{x_2 - x_1}{y_2 - y_1}\right)$$

Table B1
Parallax error while judging excursion

Calculated camera parallax error (mm)	**Error considered while judging excursion mm (inch)**
<= 5	0
6–20	12.7 (0.5 inch)
21–30	25.4 (1 inch)

APPENDIX C: H350M INJURY REFERENCE CURVES

Figure C1
Force duration corridor for neck tension force

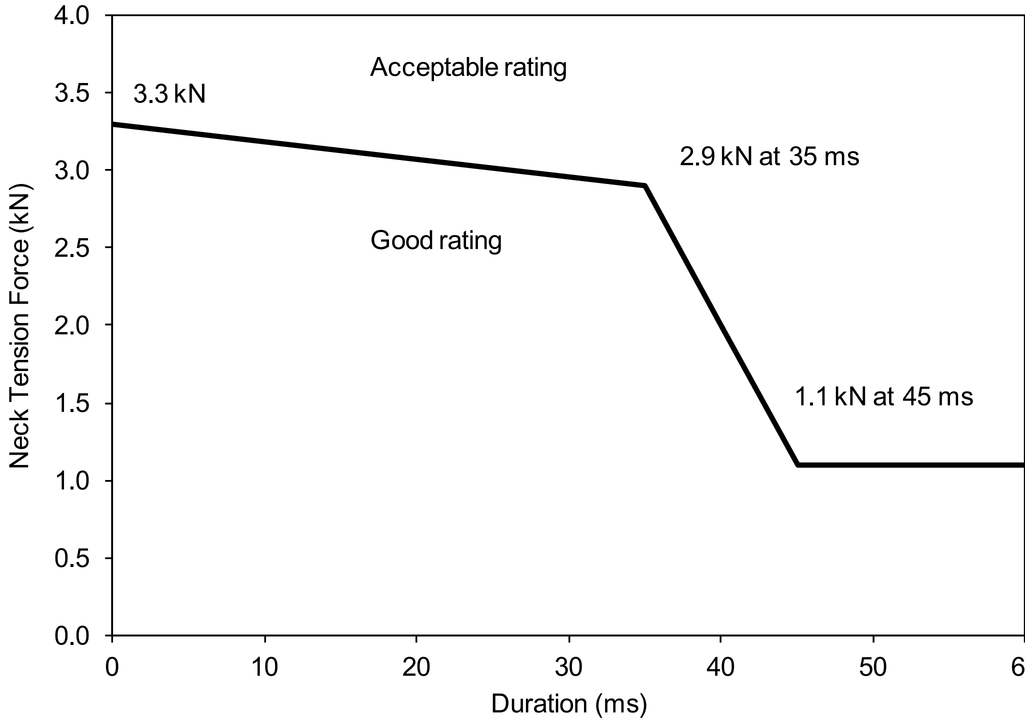


Figure C2
Force duration corridor for neck compression force

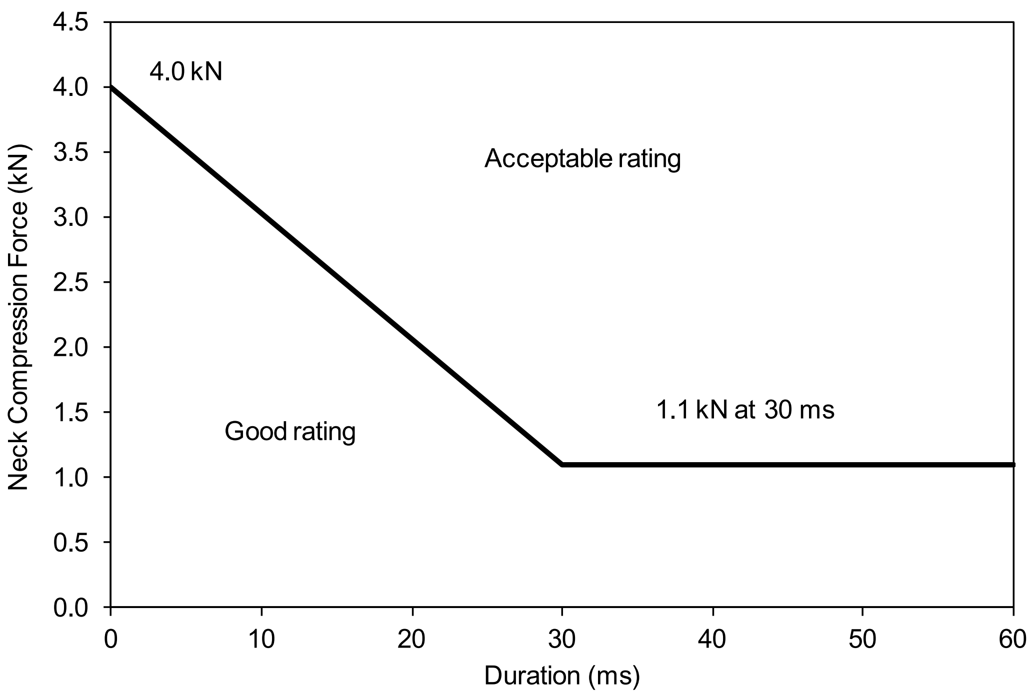


Figure C3
Force duration corridor for neck shear force

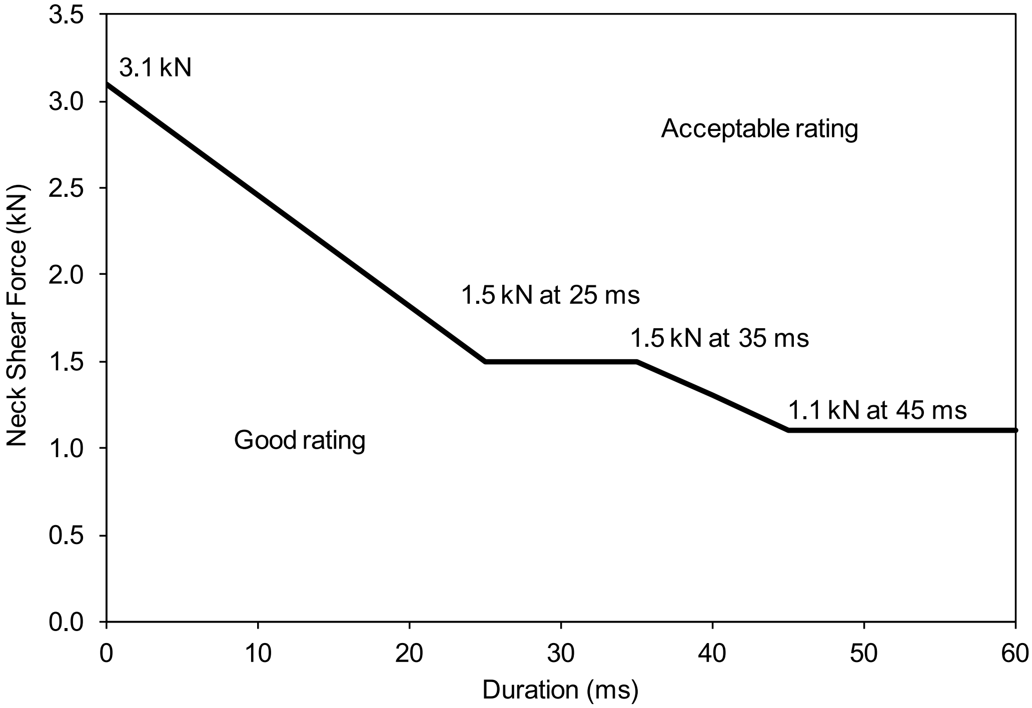


Figure C4
Integration limits for calculation of femur impulse for Hybrid III 50th dummy

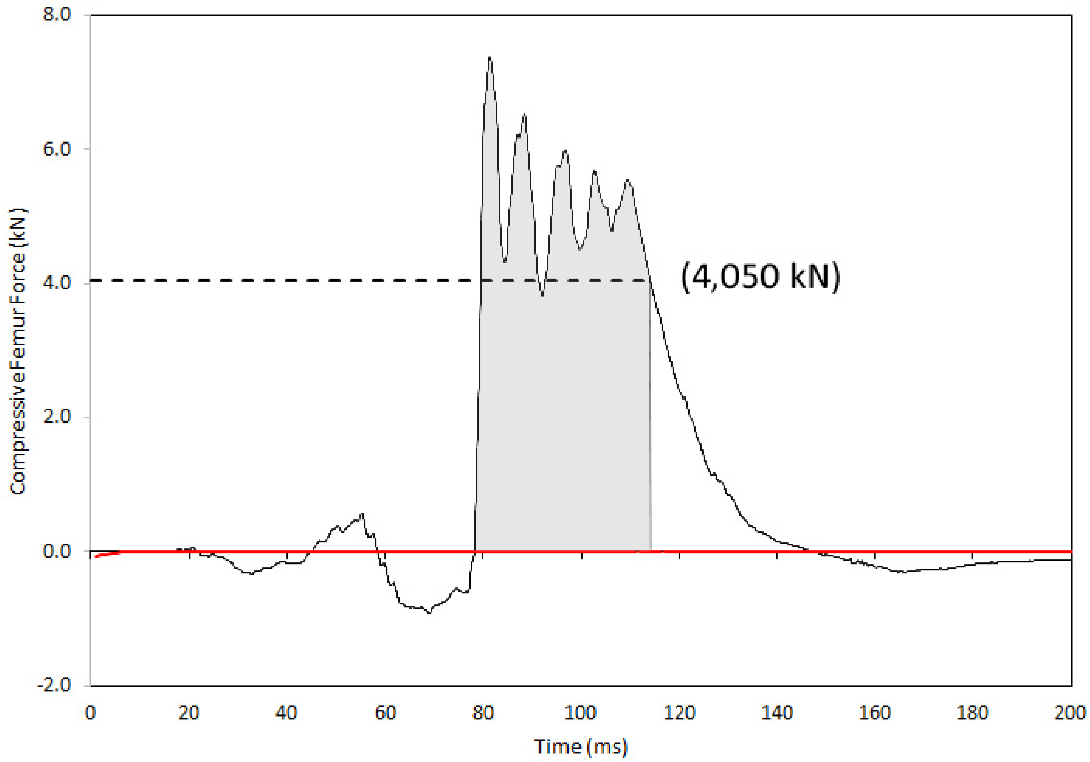


Figure C5
Force and impulse corridor limits for Knee-Thigh-Hip injury risk