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Intelligent Safety Index

Passive Safety Rating Protocol

(Version 2023)

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Passive Safety Rating Protocol

1 Scope

This document specifies the rating method for IVISTA China Intelligent Vehicle Index - Intelligent Safety Index - Passive Safety.

2 Introduction

The passive safety of the intelligent safety index includes frontal crash (small overlap frontal driver-side crash, small overlap frontal passenger-side crash and moderate overlap frontal crash) and side impact crash rating. The overall rating is carried out based on the rating results of frontal crash and side impact crash.

3 Evaluation Method

The rating method for each passive safety item is shown in Table 1 below.

Table 1 List of Passive Safety Rating Methods

S/N	Item Name		Rating Method
1	Frontal crash	Small overlap frontal driver-side crash	See Annex A for details.
2		Small overlap frontal passenger-side crash	See Annex B for details.
3		Moderate overlap frontal crash	See Annex C for details.
4	Side impact crash		See Annex D for details.

4 Overall Rating Method

The overall rating of passive safety is divided into four levels: Good (G), Acceptable (A), Marginal (M), and Poor (P).

a) The overall rating is Good (G): All of the four test items, i.e. small overlap frontal driver-side crash, small overlap frontal passenger-side crash, moderate overlap frontal crash and side impact crash, are rated as Good (G).

b) The overall rating is Acceptable (A): All of the four test items, i.e. small overlap frontal driver-side crash, small overlap frontal passenger-side crash, moderate overlap frontal crash and side impact crash, are rated as ≥ Acceptable (A).

c) The overall rating is Marginal (M): All of the four test items, i.e. small overlap frontal driver-side crash, small overlap frontal passenger-side crash, moderate overlap frontal crash and side impact crash, are rated as ≥ Marginal (M).

d) The overall rating is poor (P): other conditions that do not meet the requirements of a), b) and c) in 4.

See Table 2 for the specific rating methods.

Table 2 Overall Rating of Passive Safety

Small Overlap Frontal Driver-side Crash	Small Overlap Frontal Passenger-side Crash	Moderate Overlap Frontal Crash	Side Impact Crash	Overall Rating
All four items are rated as Good (G)				Good (G)
All four items are rated as ≥ Acceptable (A)				Acceptable (A)
All four items are rated as ≥ Marginal (M)				Marginal (M)
Others				Poor (P)

Annex A

Rating Method for Small Overlap Frontal Driver-side Crash

A.1 Introduction

The small overlap frontal driver-side crash rating includes three aspects: restraint system and ATD motion, ATD injury, and vehicle structure. This protocol elaborates on the rating methods.

A.2 Restraint system and ATD motion rating

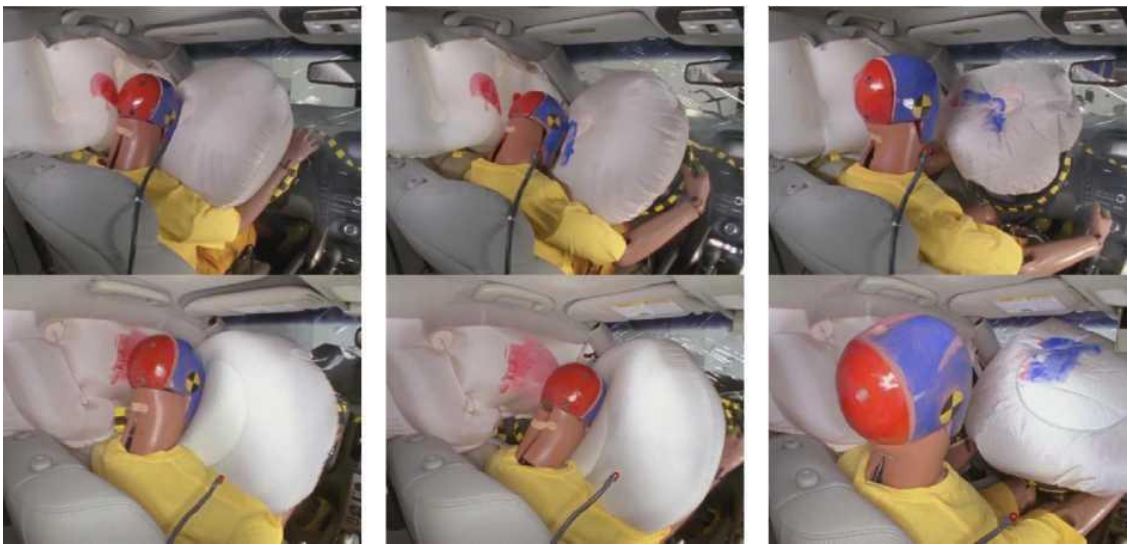
A.2.1 Front passenger restraint system and ATD motion rating

A.2.1.1 Frontal head protection

A.2.1.1.1 Stable frontal airbag action (0 defects, see Fig. A.1) means that the ATD moves forward and comes into contact with the fully deployed airbag, and then directly bounces back to the seat.

When the ATD moves forward, its head on the frontal airbag can rotate or slide, but must remain within the airbag deployment range.

If the ATD's head leaves the airbag and slides into the gap between the airbag and the door, it is considered to be an unstable contact, which will lead to 1 ~ 2 defects, unless there are additional protective measures to prevent the head from contacting the hard structure, such as the side airbag covering the A-pillar or the A-pillar airbag.



Note: The ATD moves forward and keeps in contact with the fully deployed frontal airbag until it starts to rebound.

Fig. A.1 Example of Stable Frontal Airbag Action

A.2.1.1.2 Partial frontal airbag action (1 defect, see Figs. A.2, A.3, A.4 and A.5) means that the ATD moves forward and comes into contact with the deployed airbag, but its head partially leaves the airbag and slides into the gap between the airbag and the door.

For example, the ATD's head rotates excessively, slides excessively along the frontal

airbag, or the initial contact position is the edge of the airbag, causing the ATD's head to slide into the gap between the airbag and the door.

If the additional frontal protection provided by the airbag is little when the forward tilting amount of the ATD reaches the maximum (for example, the airbag volume between the ATD and the internal structure is small), it is also considered as the partial frontal airbag action.

Note: During the crash, the ATD's head underwent the frontal airbag action briefly before sliding into the gap between the frontal airbag and the side head protection airbag (the frontal airbag is narrow and there are no other measures to prevent the head from making hard contact with the front of the airbag.).

Fig. A.2 Example of Partial Frontal Airbag Action

Note: During the crash, the ATD's head is subjected to the airbag action, but then rotates around the airbag and slides to the left, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. A.3 Example of Partial Frontal Airbag Action

Note: During the crash, the ATD's head is subjected to the frontal airbag action, and then slides directly to the left, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. A.4 Example of Partial Frontal Airbag Action

Note: During the crash, the ATD's head is subjected to the frontal airbag action, but then it moves partially around the airbag and slides to the left, and hits the A-pillar.

Fig. A.5 Example of Partial Frontal Airbag Action

A.2.1.1.3 Little frontal airbag action (2 defects, see Fig. A.6 or A.7) means that during the forward movement of the ATD, most of the head moves to the gap between the door and the frontal airbag, with little or no restraint of the airbag and no other measures to prevent the head from making hard contact with the front of the airbag.

Note: During the crash, the ATD's head hardly comes into contact with the frontal airbag before sliding to the left, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. A.6 Example of Little Frontal Airbag Action

Note: During the crash, the ATD's head does not come into contact with the frontal airbag at all, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. A.7 Example of Little Frontal Airbag Action

A.2.1.1.4 The head "bottoms out" on the airbag (1 defect): During the deep contact between the ATD's head and the airbag, if there is one or more obvious rising edges in the head acceleration curve, the starting point and the end point causing an obvious local peak value are linearly smoothed. If the local peak value is more than 5 g higher than the smoothed value for more than 3 ms, it is considered that the head "bottoms out" on the frontal airbag.

A.2.1.1.5 Excessive lateral movement of the steering wheel (1 defect) means that the center of the steering wheel moves more than 10 cm laterally.

A.2.1.1.6 Two or more hard contacts on the head (1 defect) mean two or more hard contacts resulting in a resultant head acceleration exceeding 70 g.

If there is one hard contact resulting in the resultant head acceleration exceeding 70 g, the head and neck injury rating will be degraded by one level, but the defects in the restraint system and ATD motion rating will not be counted. The contact of ATD's head with B-pillar because it rebounds due to the removal of the seat head restraint will be ignored.

A.2.1.1.7 If the frontal airbag is not deployed or not deployed in time, the restraint system and ATD motion is rated as "Poor".

A.2.1.2 Side head protection

A.2.1.2.1 Adequate front coverage after deployment of the side head protection airbag (0 defects) means that, after the side airbag (for example, the curtain airbag installed on the roof or on the door or the side airbag with head protection function installed on the seat) deploys, the airbag chamber extends forward at least to the orthogonal vertical plane of the center of the steering wheel at its front-most (driving direction) telescopic position (if adjustable). If the side head protection airbag is stuck during deployment, it cannot be judged as adequate front coverage after deployment of the side head protection airbag.

A.2.1.2.2 Limited front coverage after deployment of the side head protection airbag (1 defect) means that the side airbag deploys but does not extend to the orthogonal vertical plane of the center of the steering wheel at its front-most telescopic position (if adjustable). If the side head protection airbag meets the *Side Curtain Ejection Mitigation Test Protocol*, the defect will not be counted.

A.2.1.2.3 Side head protection airbag not deployed (2 defects) means that the side airbag is not equipped or not deployed, or fails to provide effective side head protection after deployment. For example, the ATD's head moves out of the coverage of the side airbag.

A.2.1.2.4 Excessive lateral displacement of head (1 defect, see Fig. A.8) means that more than half of the head moves to the outside of the contour of the driver's side window before deformation during the crash.

Note: When the ATD moves outward, its head moves to the outside of the contour of the driver's side window before deformation as affected by the internal structure of the vehicle and the lack of the side head protection airbag.

Fig. A.8 Example of Excessive Lateral Displacement of Head

A.2.1.3 Frontal chest protection

A.2.1.3.1 Excessive vertical movement of the steering wheel (1 defect) means that the center of the steering wheel moves vertically (in Z direction) for more than 10 cm.

A.2.1.3.2 Excessive lateral movement of the steering wheel (1 defect) means that the center of the steering wheel moves laterally (in Y direction) for more than 15 cm.

A.2.1.4 Passenger protection and others

A.2.1.4.1 Excessive forward leaning of passenger (1 defect) means that the maximum longitudinal displacement of the ATD exceeds 250 mm.

This defect does not apply if the following three conditions exist at the same time:

1) The ATD is in stable contact with the frontal airbag;

2) Lateral movement of the steering wheel is less than or equal to 10 cm;

3) Vertical movement of the steering wheel is less than or equal to 10 cm.

If the belt slack is more than 100 mm during the test, it is judged that the passenger leans forward excessively.

A.2.1.4.2 Passenger at risk of burn (1 defect) means that ATD body parts or clothes are melted or burned by the hot gas generated by airbag detonation.

A.2.1.4.3 Flying out of interior trim panels/hard components from the vehicle (1 defect) means that interior trim panels with sharp edges and corners (with a radius of curvature less than 2.5 mm) or hard components fly out from the vehicle and hit the ATD's face with a risk of injury during the crash.

A.2.1.4.4 Failure to unlock the seat belt or excessive unlocking force (1 defect) means that the seat belt cannot be unlocked or the unlocking force of the seat belt buckle is greater than 60 N to release the ATD from the restraint system after the crash.

A.2.1.4.5 Seat instability (1 defect) means that the seat adjustment and the part related to the passenger position are affected by the deformation of the vehicle floor or the seat lifting structure (for example, the relative vertical displacement between two seat fixing points is ≥ 6 cm, or some other deformation causes the seat cushion assembly to move outward or forward). However, this defect can be determined only when the seat cushion frame moves outward or forward to the extent that it has a negative impact on the ATD motion and directly causes the ATD to move forward or outward excessively.

A.2.1.4.6 Seat fixation failure (restraint system and ATD motion rated as "Poor") means that the seat fixing point is broken or the sliding rail is obviously displaced.

A.2.1.4.7 If the door is opened or separated, the restraint system and ATD motion is rated as "Poor".

Table A.1 Restraint System and ATD Motion Defects (Driver-side ATD)

Frontal head protection	
Stable frontal airbag action	0 defects
Partial frontal airbag action	1 defect
Little frontal airbag action	2 defects
The head "bottoms out" on the airbag	1 defect
Excessive lateral movement of steering wheel (>10 cm)	1 defect
Two or more hard contacts on the head	1 defect
Frontal airbag not deployed or not deployed in time	Restraint system and ATD motion rated as "Poor"
Side head protection	
Frontal head protection	
Adequate front coverage after deployment of the side head protection airbag	0 defects
Limited front coverage after deployment of the side head protection airbag	1 defect
Side head protection airbag not deployed	2 defects
Excessive lateral displacement of head	1 defect
Frontal chest protection	
Excessive vertical movement of steering wheel (>10 cm)	1 defect
Excessive lateral movement of steering wheel (>15 cm)	1 defect
Passenger protection and others	
Excessive forward leaning of passenger	1 defect
Passenger at risk of burn	1 defect
Flying out of interior trim panels/hard components from the vehicle	1 defect
Failure to unlock the seat belt or excessive unlocking force	1 defect
Seat instability	1 defect
Seat fixation failure	Restraint system and ATD motion rated as "Poor"
Door opened or separated	Restraint system and ATD motion rated as "Poor"
Overall Rating of Restraint System and ATD Motion	
Good	0-1 defect
Acceptable	2-3 defects
Marginal	4-5 defects
Poor	6+ defects

A.2.2 Rear passenger restraint system and ATD motion rating

A.2.2.1 Head protection

A.2.2.1.1 Adequate side head protection (0 defects) means that the side head protection airbag effectively protects the head.

A.2.2.1.2 Limited side head protection (1 defect) means that the side head protection airbag does not effectively protect the head (the rear ATD's head is stuck at the bottom of the side head protection airbag during a crash, or part of the ATD's head moves beyond the height of the door window frame).

A.2.2.1.3 Side head protection airbag not deployed (2 defects) means that the side head

protection airbag is not equipped or not deployed, or fails to provide side head protection after deployment. For example, the rear ATD's head slides out of the coverage of the side head protection airbag during a crash.

A.2.2.1.4 Hard contact of head (1 defect) means the contact between head and door interior trim or B-pillar interior trim, etc. with a resultant acceleration exceeding 70 g.

A.2.2.1.5 Excessive lateral displacement of head (1 defect) means that more than half of the head moves to the outside of the contour of the rear passenger side window before deformation during the crash.

A.2.2.2 Passenger protection and others

A.2.2.2.1 Excessive forward leaning of passenger (1 defect) means that the rear ATD's head comes into contact with the front seat.

A.2.2.2.2 Flying out of interior trim panels/hard components from the vehicle (1 defect) means that interior trim panels with sharp edges and corners (with a radius of curvature less than 2.5 mm) or hard components fly out from the vehicle and hit the ATD's face with a risk of injury during the crash.

A.2.2.2.3 Failure to unlock the seat belt or excessive unlocking force (1 defect) means that the seat belt cannot be unlocked or the unlocking force of the seat belt buckle is greater than 60 N to release the ATD from the restraint system after the crash.

A.2.2.2.4 ATD submarining means the sudden drop of the force on iliac bone on either the left or the right side of the ATD within 1 ms, which can be confirmed by a high-speed camera.

A.2.2.2.5 Seat instability (1 defect) means that the seat adjustment and the part related to the passenger position are affected by the deformation of the vehicle floor or the seat lifting structure (for example, the relative vertical displacement between two seat fixing points is ≥ 6 cm, or some other deformation causes the seat cushion assembly to move outward and/or forward). However, this defect can be determined only when the seat cushion frame moves outward and/or forward to the extent that it has a negative impact on the ATD motion and directly causes the ATD to move forward or outward excessively.

A.2.2.2.6 Seat fixing point failure (restraint system and ATD motion rated as "Poor") means that the seat fixing point is broken or the sliding rail is obviously displaced.

A.2.2.2.7 If the door is opened or separated, the restraint system and ATD motion is rated as "Poor".

Table A.2 Restraint System and ATD Motion Defects (Rear Passenger ATD)

Head protection	
Adequate side head protection	0 defects
Limited side head protection	1 defect
Side head protection airbag not deployed	2 defects
Hard contact of head	1 defect
Excessive lateral displacement of head	1 defect
Passenger protection and others	
Excessive forward leaning of passenger	1 defect

Flying out of interior trim panels/hard components from the vehicle	1 defect
Failure to unlock the seat belt or excessive unlocking force	1 defect
ATD submarining	Restraint system and ATD motion rating downgraded by one level
Seat instability	1 defect
Seat fixation failure	Restraint system and ATD motion rated as "Poor"
Door opened or separated	Restraint system and ATD motion rated as "Poor"
Overall Rating of Restraint System and ATD Motion	
Good	0 defects
Acceptable	1 defect
Marginal	2-3 defects
Poor	4+ defects

A.3 ATD injury rating

A.3.1 Front passenger injury rating

Rate the ATD injury with the measured injury values of the Hybrid III 50th ATD. See Table A.3 for ATD measurement parameters and filtering level.

Table A.3 ATD Measurement Parameters and Filtering Level

Measuring Parts	Measurement Parameters	Filtering Level
Head	Acceleration A_x, A_y, A_z	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Neck	Force F_x, F_y, F_z	CFC 1000
	Moment M_y	CFC 600
Chest	Acceleration A_x, A_y, A_z	CFC 180
	Compression deformation D	CFC 600
Thigh and hip	Compression force on thigh (left/right) F_z	CFC 600
	Sliding displacement of knee joint (left/right) D	CFC 180
Tibia	Force on upper tibia and moment (left/right) F_z, M_x, M_y	CFC 600
	Force on lower tibia and moment (left/right) F_z, M_x, M_y	CFC 600
Foot	Acceleration (left/right) A_x, A_z	CFC 180

The ATD injury rating involves four parts: head and neck, chest, thigh and hip, tibia and foot.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part. Thigh/hip and tibia/foot are rated according to the lower rating of the left or right side. Table A.4 shows the limit range of rating indexes of four levels: good, acceptable, marginal and poor.

A.3.1.1 Head and neck

Head rating indexes: HIC_{15}, HIC_{36} (for reference but not for rating), cumulative 3 ms resultant acceleration (for reference but not for rating), and maximum resultant head acceleration.

If there is one hard contact resulting in the resultant head acceleration exceeding 70 g, the head and neck injury rating will be degraded by one level. See Fig. A.9 for details of head and neck injuries in multiple crashes.

Neck rating indexes: N_{ij}, axial tensile force Fz, axial compressive force Fz, shear force Fx, compressive bending moment My (for reference but not for rating), and tensile bending moment My (for reference but not for rating).

If the curves of duration vs. axial tensile force Fz, axial compressive force Fz and shear force Fx on the neck go beyond the limits of "good" shown in Figs. A.10, A.11 and A.12, head and neck rating "good" will be degraded to "acceptable".

Head calculation:

$$HIC = (t_2 - t_1)\left[\frac{\int_{t_1}^{t_2} A_R.\,dt}{(t_2 - t_1)}\right]^{2.5}$$

$$A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Where, *Ax*, *Ay* and *Az* are acceleration values of the head in three directions, in g.

t_2-t_1≤15 ms (for rating), t_2-t_1≤36 ms (for reference).

Neck calculation:

$$N_{ij} = (F_z/F_{zc}) + \left(M_{OCy}/M_{yc}\right)$$

$$M_{OCy} = M_y - (D \bullet F_x)$$

Where, *Fz* is the axial force on neck, in N;

Fzc is the critical axial force on neck, in N;

Fx is the axial shear force on neck, in N;

My is the tensile/compressive bending moment of neck, in Nm;

Myc is the critical tensile/compressive bending moment of neck, in Nm;

D (0.01778), in m, is the distance between the center of the neck force sensor and the center of the head-neck connecting shaft.

Table A.4 Critical Values for N_{ij} Calculation

ATD Type	*Fzc* - axial tensile force	*Fzc* - axial compressive force	*Myc* - compressive bending moment	*Myc* - tensile bending moment
Hybrid III 50th	6806N	-6160N	310Nm	-135Nm

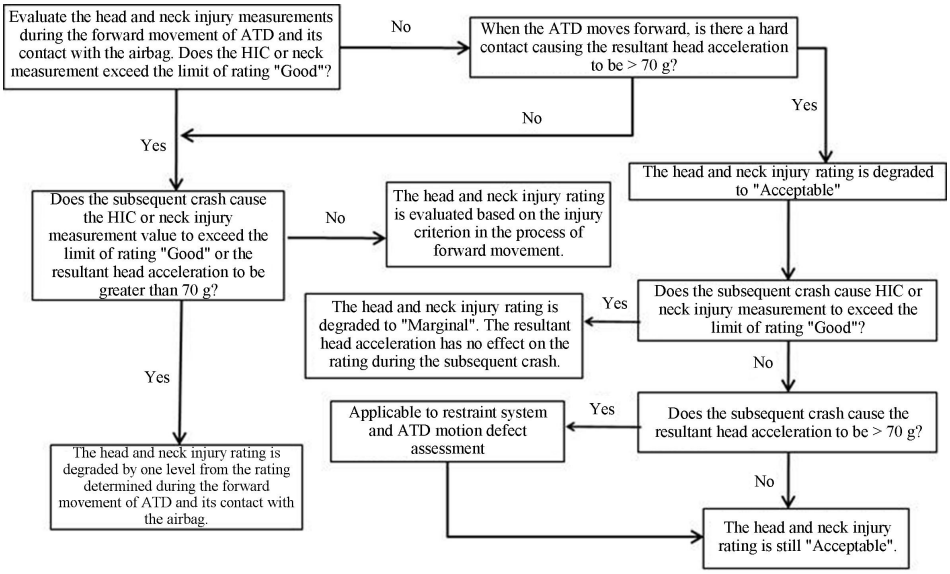


Fig. A.9 Flow Chart of Head and Neck Injury Rating in Multiple Crashes

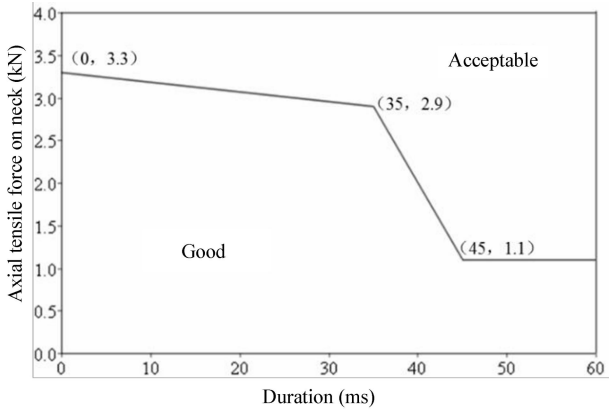


Fig. A.10 Curve of Duration vs. Tensile Force on Neck Fz

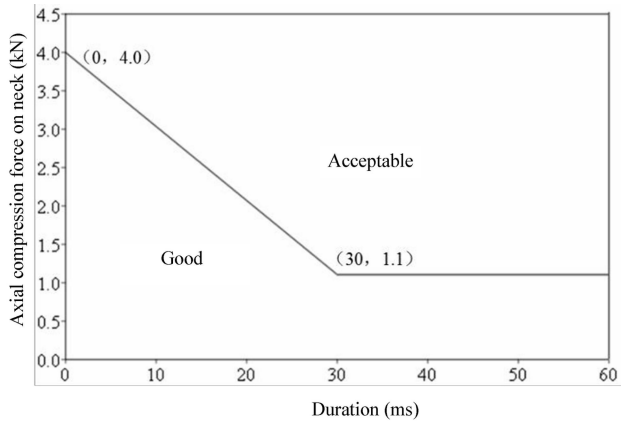


Fig. A.11 Curve of Duration vs. Compressive Force on Neck Fz

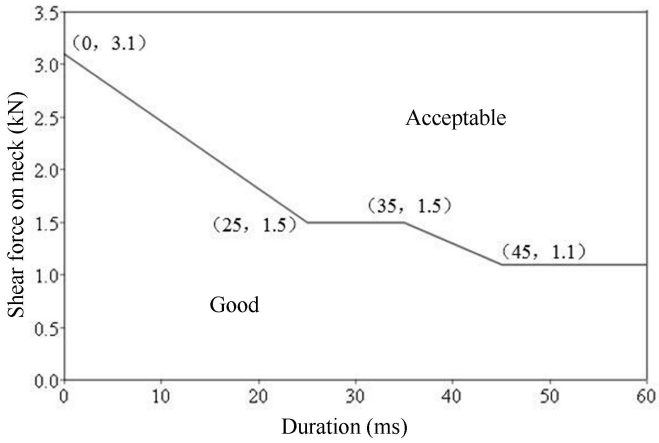


Fig. A.12 Curve of Duration vs. Shear Force on Neck Fx

A.3.1.2 Chest

Chest rating indexes: continuous acceleration A_3 ms, compression deformation D, compression velocity V, and viscous criterion VC.

VC calculation:

$$(VC)_t = 1.3V_t \times C_t$$

$$C_t = \frac{D_t}{0.229}$$

The chest compression velocity at time point t is calculated from the filtered compression deformation (filtering level CFC60).

$$V_t = \frac{8\left[D_{(t+1)} - D_{(t-1)}\right] - \left[D_{(t+2)} - D_{(t-2)}\right]}{12\delta t}$$

Where, D_t is the deformation at time point t, in m; δt is the time interval for compression deformation measurement, in s.

A.3.1.3 Thigh and hip

Thigh and hip rating indexes: knee-thigh-hip (KTH) injury risk, compressive force Fz on thigh (for reference but not for rating).

KTH injury risk is determined according to Fig. A.14 based on the compressive force and impulse value of each thigh. The impulse value is obtained by integrating the force on thigh from the beginning of thigh compression to 4050 N after the peak force is reached; as shown in Fig. A.13.

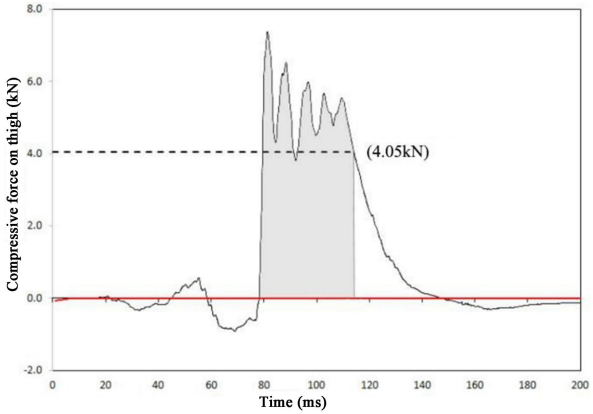


Fig. A.13 Thigh Impulse on Hybrid III 50th ATD

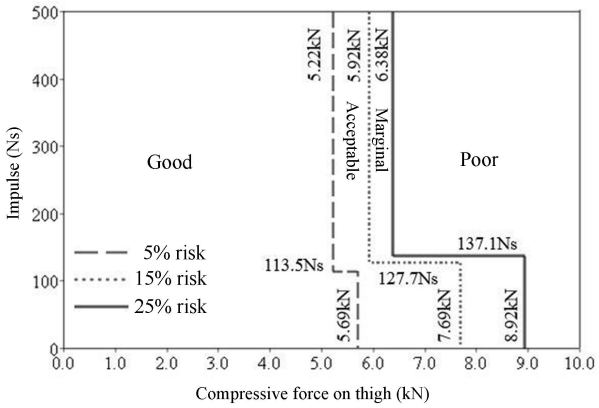


Fig. A.14 KTH Injury Risk

A.3.1.4 Tibia and foot

Tibia rating indexes: axial compressive force on upper tibia and lower tibia Fz, knee joint sliding displacement D, and tibia index TI.

Tibia index TI is calculated with the adjusted bending moment My.

$$M_{\text{Y upper adjustment}} = M_{\text{Y upper measured value}} - [(F_{\text{Z tibia}})\ (0.02832)]$$

$$M_{\text{Y lower adjustment}} = M_{\text{Y lower measured value}} + [(F_{\text{Z tibia}})\ (0.006398)]$$

Note: The bending moment is measured in Nm, and the force in N.

TI calculation:

$$M_R = \sqrt{(M_X)^2 + \left(M_{\text{Y adjustment}}\right)^2}$$

$$\text{TI} = |M_R/(M_C)_R| + |F_Z/(F_C)_z|$$

Where, M_X is the bending moment around X axis, $M_{Y\ \text{adjustment}}$ is the adjusted bending moment around Y axis, $(M_C)_R$ is critical bending moment, F_Z is axial compressive force in Z direction, and $(F_C)_Z$ is critical compressive force in Z direction.

Foot rating index: maximum resultant foot acceleration.

Table A.5 ATD Injury Rating

Body Parts	Parameters	Good	Acceptable	Marginal	Poor
Head and neck	HIC_{15}	≤560	≤700	≤840	＞840
	N_{ij}	≤0.80	≤1.00	≤1.20	＞1.20
	Tensile force F_Z (kN)*	≤2.6	≤3.3	≤4.0	＞4.0
	Compressive force F_Z (kN)*	≤3.2	≤4.0	≤4.8	＞4.8
Chest	Acceleration A_3 ms (g)	≤60	≤75	≤90	＞90
	Compression deformation D (mm)	≤50	≤60	≤75	＞75
	Compression velocity V (m/s)	≤6.6	≤8.2	≤9.8	＞9.8
	Viscous criterion VC (m/s)	≤0.8	≤1.0	≤1.2	＞1.2
Thigh and hip	KTH Injury Risk	≤5%	≤15%	≤25%	＞25%
Tibia and foot	Knee joint sliding displacement D (mm)	≤12	≤15	≤18	＞18
	Tibia index (upper and lower), TI	≤0.80	≤1.00	≤1.20	＞1.20
	Axial force on tibia F_Z (kN)	≤4.0	≤6.0	≤8.0	＞8.0
	Maximum resultant foot acceleration (Ag)	≤150	≤200	≤260	＞260

* See Fig. A.10 and Fig. A.11 for curves of duration vs. axial force on neck.

A.3.2 Rear passenger injury rating

Rate the ATD injury with the measured injury values of the Hybrid III 5th ATD. See Table A.6 for ATD measurement parameters and filtering level.

Table A.6 ATD Measurement Parameters and Filtering Level

Measuring Parts	Measurement Parameters	Filtering Level
Head	Acceleration Ax, Ay, Az	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Neck	Force Fx, Fy, Fz	CFC 1000
	Moment My	CFC 600
Chest	Acceleration Ax, Ay, Az	CFC 180
	Compression deformation D	CFC 600
Thigh and hip	Compression force on thigh (left/right) Fz	CFC 600
	Sliding displacement of knee joint (left/right) D	CFC 180
	Force on iliac bone (left/right) Fx	CFC 180
	Force on lumbar spine	CFC 600
	Pelvic acceleration Ax, Az	CFC 1000

The injury rating of ATD involves three parts: head and neck, chest, and thigh and hip.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part. Thigh/hip is rated according to the lower rating on the left or right side. Table A.7 shows the limit range of rating indexes of four levels: good, acceptable, marginal

and poor.

A.3.2.1 Head and neck

Head rating indexes: HIC_{15}, cumulative 3 ms resultant acceleration.

Head HIC is also calculated with the Hybrid III 50th ATD.

Neck rating indexes: shear force Fx, axial tensile force Fz and tensile bending moment My.

If the peak resultant head acceleration exceeds 70 g due to hard contact between head and vehicle, the head and neck injury rating will be degraded by one level.

A.3.2.2 Chest

Chest rating indexes: compression deformation D, and viscous criterion VC.

The viscous criterion VC is also calculated with Hybrid III 50th ATD, and Ct calculation formula is as follows:

$$C_t = \frac{D_t}{0.187}$$

A.3.2.3 Thigh and hip

Thigh and hip rating indexes: compressive force on left and right thighs Fz, force on left and right iliac bones (reference value), and knee joint sliding displacement D (reference value).

Table A.7 ATD Injury Rating

Body Parts	Parameters	Good	Acceptable	Marginal	Poor
Head and neck	HIC_{15}	≤560	≤700	≤840	＞840
	Acceleration A_3 ms (g)	≤72	≤76	≤80	＞80
	Shear force Fx (kN)	≤1.20	≤1.58	≤1.95	＞1.95
	Tensile force Fz (kN)	≤2.10	≤2.62	≤3.14	＞3.14
	Tensile bending moment My (Nm)	≤36	≤43	≤49	＞49
Chest	Compression deformation D (mm)	≤41.0	≤49.2	≤61.5	＞61.5
	Viscous criterion VC (m/s)	≤0.8	≤1.0	≤1.2	＞1.2
Thigh and hip	Compressive force Fz (kN)	≤5.0	≤6.2	≤7.4	＞7.4

A.4 Vehicle Structure Rating

A.4.1 Rating by intrusion measurement

The vehicle structure is rated by intrusion measurement (see Fig. A.15), and the rating is corrected (degraded) according to the qualitative observation result of the structural integrity of the passenger compartment.

Measuring points are distributed in two areas: the lower part and the upper part of the

passenger compartment. The lower part of the passenger compartment includes A-pillar lower hinge, left footrest, left toepan, brake pedal, parking brake pedal and rocker panel; the upper part of the passenger compartment includes steering column, A-pillar upper hinge, upper instrument panel and lower left instrument panel.

Compare the X-Y-Z resultant displacement of A-pillar lower hinge, left footrest, left toepan, brake pedal, parking brake pedal, A-pillar upper hinge, upper instrument panel and lower left instrument panel with the rating reference value (see Fig. A.15). For all measuring points, if they move forward along X axis (away from the driver seat), only the Y-Z resultant displacement is used for comparison with the rating reference value. For the positions at A-pillar upper hinge, A-pillar lower hinge and parking brake pedal, if the measuring points move to the left (outside) along Y axis, only the X-Z resultant displacement is used for comparison with the rating reference value. For the steering column, only the backward X-direction displacement is used for comparison with the rating reference value. For the rating of A-pillar upper hinge and A-pillar lower hinge, take the maximum resultant displacement of three positions respectively. For the rocker panel, only the inward Y-direction displacement is compared with the rating reference value, and the Y-direction displacement is the average value of three positions on the rocker panel.

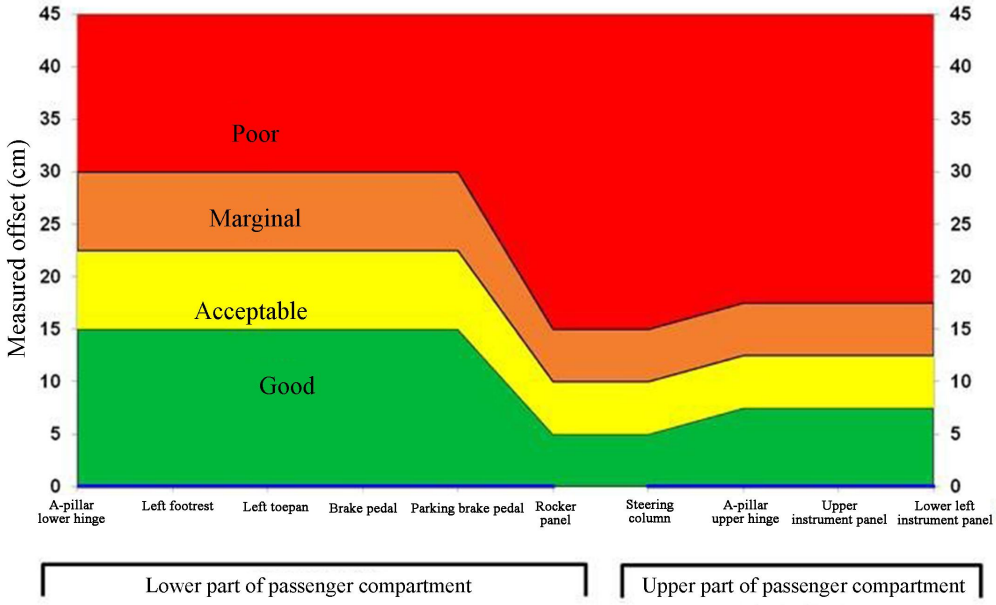


Fig. A.15 Passenger Compartment Intrusion Rating

The lower part and upper part of the passenger compartment are rated separately. If the rating is not degraded according to qualitative observation result, the overall structure rating is the lower rating of the lower and upper parts of the passenger compartment.

For the lower part or the upper part of the passenger compartment: If the intrusion measurement falls within different rating ranges, the structure rating is the rating for the area with the most measured values, but it shall not be more than one level higher than the rating for the area with the worst measured value. If half of the measurement results are in the area of the same rating, while the other half in the area of another rating, the structure rating is the lower rating. The higher rating is taken if the intrusion lies on the boundary of two different ratings.

The structure measuring points at the upper and lower parts of the passenger

compartment are rated according to the thresholds of rating indexes. See Table A.8 for specific rating requirements:

Table A.8 Vehicle Structure Rating

Rating Object		Evaluation Index	Good	Acceptable	Marginal	Poor
Lower part of passenger compartment	A-pillar lower hinge	Resultant displacement (cm)	≤15	≤22.5	≤30	>30
	Left footrest					
	Left toepan					
	Brake pedal					
	Parking brake pedal					
	Rocker panel	Y-direction intrusion (cm)	≤5	≤10	≤15	>15
Upper part of passenger compartment	Steering column	X-direction intrusion (cm)	≤5	≤10	≤15	>15
	A-pillar upper hinge	Resultant displacement (cm)	≤7.5	≤12.5	≤17.5	>17.5
	Upper instrument panel					
	Lower left instrument panel					

A.4.2 Qualitative observation of vehicle structure rating

If the ATD's feet are stuck and can only be taken out with tools, the hinge pillar is completely torn, and the front wall is torn in a large area (for example, the tearing length is greater than 20 cm, and the width is greater than 5 cm), the vehicle structure rating shall be degraded by one level from the rating of intrusion measurement.

A.4.3 Integrity of fuel system and high voltage system

If there is obvious fuel leakage or damage to the high voltage system (e.g., electric drive system) during the test, the vehicle structure rating and overall rating will be downgraded to "Poor".

Obvious fuel leakage means that more than 28 g of fuel leaks from crash to vehicle standstill, and more than 142 g leaks in the following 5 min, and 28 g leaks per minute in the next 25 min.

The high-voltage system must meet the requirements of electrolyte leakage, rechargeable electrical energy storage system (REESS) safety and electric shock protection in GB/T 31498-2021 *Post Crash Safety Requirement for Electric Vehicle*, so as to avoid level degrading. The specific requirements are summarized as follows:

- Requirements for electrolyte leakage

  Within 30 min after the crash, there shall be no electrolyte overflowing from the REESS to the passenger compartment and no over 5.0 L of electrolyte overflowing from the REESS.

- Requirements for REESS safety

① The REESS located in the passenger compartment shall remain in the installation position, REESS components shall be kept within the housing, and any part of the REESS located outside the passenger compartment shall not enter the passenger compartment.

② Within 30 min after the end of crash, the REESS shall not explode or catch fire.

- Requirements for electric shock protection

Electric shock protection involves four rating indexes: voltage, electric energy, physical protection and insulation resistance requirements. Each high voltage bus shall meet at least one of the four rating indexes. If the crash test is carried out with the REESS of the vehicle actively disconnected from the balance of electric power system, the balance of electric power system of the vehicle shall meet the requirements for physical protection or insulation resistance; the REESS and high voltage bus for charging shall meet one of the four rating indexes:

① Voltage requirements

The voltages V_b, V_1 and V_2 of high voltage bus measured according to GB/T 31498-2021 *Post Crash Safety Requirement for Electric Vehicle* shall not exceed 30 V AC or 60 V DC.

② Electric energy requirements

Both the total electric energy TE on the high voltage bus and the energy (TEy1, TEy2) stored in Y-capacitor shall be less than 0.2 J.

③ Physical protection

To prevent direct contact with high-voltage live parts, the vehicle shall have IPXXB protection after the crash; to prevent electric shock injury caused by indirect contact, the resistance between all exposed conductive parts and electric chassis shall be less than 0.1 Ω as measured with a current higher than 0.2 A. This requirement is deemed to be met when the electrical connection is made by welding.

④ Insulation resistance

If the AC high voltage bus and the DC high voltage bus are subject to conductive insulation with each other, the insulation resistance between the DC high voltage bus and the electric chassis shall be greater than or equal to 100 Ω/V, and the insulation resistance between the AC high voltage bus and the electric chassis shall be greater than or equal to 500 Ω/V.

If the AC high voltage bus and the DC high voltage bus are conductively connected with each other, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 500 Ω/V. After the crash, if the IP rating of all AC high voltage buses reaches IPXXB or the AC voltage is equal to or less than 30 V, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 100 Ω/V.

A.5 Overall rating

The overall rating is based on the vehicle structure, the measured injuries of the driver's head and neck, chest, thighs and hips, and tibias and feet and the rear passengers' heads and necks, chests, thighs and hips, and the front and rear ATD restraint system and ATD motion, and calculated according to Table A.9.

Table A.9 Overall Rating

Rating Item	Level			
	Good (G)	Acceptable (A)	Marginal (M)	Poor (P)
Vehicle structure	0	2	6	10
Driver				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Tibia and foot	0	1	2	4
Restraint system and ATD motion	0	2	6	10
Rear passengers				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Restraint system and ATD motion	0	2	6	10
Overall rating limit	0-3	4-9	10-19	20+

Note: If two doors in the same row cannot be opened from outside normally without tools after the test, the overall rating will be degraded by one level.

Annex B

Rating Method for Small Overlap Frontal Passenger-side Crash

B.1 Introduction

The small overlap frontal passenger-side crash rating includes three aspects: restraint system & ATD motion, ATD injury, and vehicle structure. This protocol elaborates on the rating methods.

B.2 Restraint system and ATD motion rating

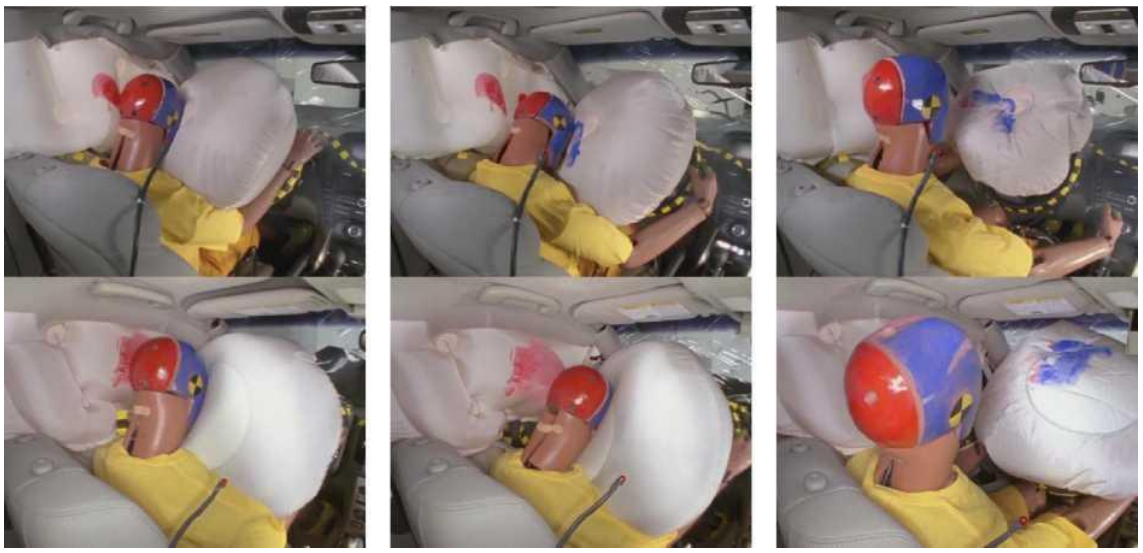
B.2.1 Front passenger restraint system and ATD motion rating

B.2.1.1 Frontal head protection

B.2.1.1.1 Stable frontal airbag action (0 defects, see Fig. B.1) means that the ATD moves forward and comes into contact with the fully deployed airbag, and then directly bounces back to the seat.

When the ATD moves forward, its head on the frontal airbag can rotate or slide, but must remain within the airbag deployment range.

If the ATD's head leaves the airbag and slides into the gap between the airbag and the door, it is considered to be an unstable contact, which will lead to 1 ~ 2 defects, unless there are additional protective measures to prevent the head from contacting the hard structure, such as the side airbag covering the A-pillar or the A-pillar airbag.



Note: The ATD moves forward and keeps in contact with the fully deployed frontal airbag until it starts to rebound.

Fig. B.1 Example of Stable Frontal Airbag Action

B.2.1.1.2 Partial frontal airbag action (1 defect, see Figs. B.2, B.3, B.4 and B.5) means that the ATD moves forward and comes into contact with the deployed airbag, but its head partially leaves the airbag and slides into the gap between the airbag and the door. For example, the ATD's head rotates excessively, slides excessively along the frontal airbag, or

the initial contact position is the edge of the airbag, causing the ATD's head to slide into the gap between the airbag and the door.

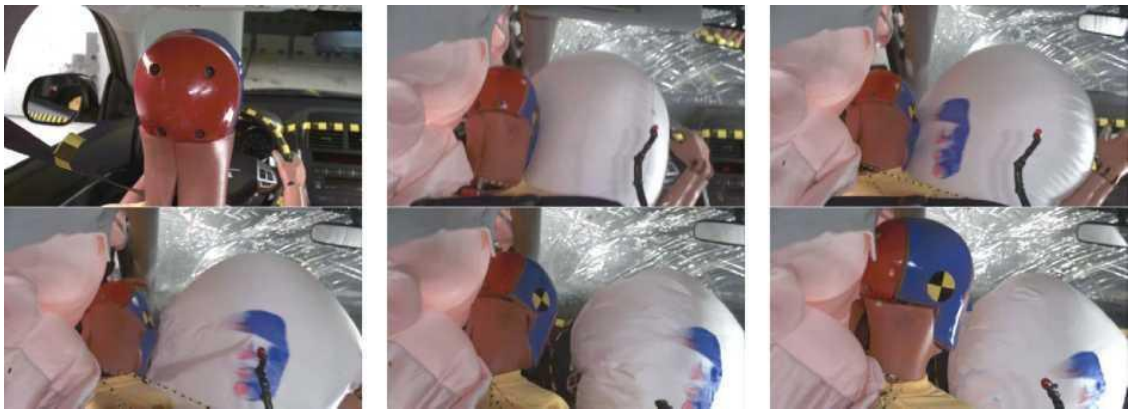
If the additional frontal protection provided by the airbag is little when the forward tilting amount of the ATD reaches the maximum (for example, the airbag volume between the ATD and the internal structure is small), it is also considered as the partial frontal airbag action.

Note: During the crash, the ATD's head underwent the frontal airbag action briefly before sliding into the gap between the frontal airbag and the side head protection airbag (the frontal airbag is narrow and there are no other measures to prevent the head from making hard contact with the front of the airbag.).

Fig. B.2 Example of Partial Frontal Airbag Action

Note: During the crash, the ATD's head is subjected to the airbag action, but then rotates around the airbag and slides to the left, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. B.3 Example of Partial Frontal Airbag Action



Note: During the crash, the ATD's head is subjected to the frontal airbag action, and then slides directly to the left, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. B.4 Example of Partial Frontal Airbag Action

Note: During the crash, the ATD's head is subjected to the frontal airbag action, but then it moves partially around the airbag and slides to the left, and hits the A-pillar.

Fig. B.5 Example of Partial Frontal Airbag Action

B.2.1.1.3 Little frontal airbag action (2 defects, see Fig. B.6 or B.7) means that during the forward movement of the ATD, most of the head moves to the gap between the door and the frontal airbag, with little or no restraint of the airbag and no other measures to prevent the head from making hard contact with the front of the airbag.

Note: During the crash, the ATD's head hardly comes into contact with the frontal airbag before sliding to the left, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. B.6 Example of Little Frontal Airbag Action

Note: During the crash, the ATD's head does not come into contact with the frontal airbag at all, and there are no other measures to prevent the head from making hard contact with the front of the airbag.

Fig. B.7 Example of Little Frontal Airbag Action

B.2.1.1.4 The head "bottoms out" on the airbag (1 defect): During the deep contact between the ATD's head and the airbag, if there is one or more obvious rising edges in the head acceleration curve, the starting point and the end point causing an obvious local peak value are linearly smoothed. If the local peak value is more than 5 g higher than the smoothed value

for more than 3 ms, it is considered that the head "bottoms out" on the frontal airbag.

B.2.1.1.5 Excessive lateral movement of the steering wheel (1 defect) means that the center of the steering wheel moves more than 10 cm laterally.

B.2.1.1.6 Two or more hard contacts on the head (1 defect) mean two or more hard contacts resulting in a resultant head acceleration exceeding 70 g.

If there is one hard contact resulting in the resultant head acceleration exceeding 70 g, the head and neck injury rating will be degraded by one level, but the defects in the restraint system and ATD motion rating will not be counted. The contact of ATD's head with B-pillar because it rebounds due to the removal of the seat head restraint will be ignored.

B.2.1.1.7 If the frontal airbag is not deployed or not deployed in time, the restraint system and ATD motion is rated as "Poor".

B.2.1.2 Side head protection

B.2.1.2.1 Adequate front coverage after deployment of the side head protection airbag (0 defects) means that, after the side airbag (for example, the curtain airbag installed on the roof or on the door or the side airbag with head protection function installed on the seat) deploys, the airbag chamber extends forward at least to the orthogonal vertical plane of the center of the steering wheel at its front-most (driving direction) telescopic position (if adjustable). If the side head protection airbag is stuck during deployment, it cannot be judged as adequate front coverage after deployment of the side head protection airbag.

B.2.1.2.2 Limited front coverage after deployment of the side head protection airbag (1 defect) means that the side airbag deploys but does not extend to the orthogonal vertical plane of the center of the steering wheel at its front-most telescopic position (if adjustable). If the side head protection airbag meets the *Side Curtain Ejection Mitigation Test Protocol*, the defect will not be counted.

B.2.1.2.3 Side head protection airbag not deployed (2 defects) means that the side airbag is not equipped or not deployed, or fails to provide effective side head protection after deployment. For example, the ATD's head moves out of the coverage of the side airbag.

B.2.1.2.4 Excessive lateral displacement of head (1 defect, see Fig. B.8) means that more than half of the head moves to the outside of the contour of the passenger side window before deformation during the crash.

Note: When the ATD moves outward, its head moves to the outside of the contour of the driver's side window before deformation as affected by the internal structure of the vehicle and the lack of the side head protection airbag.

Fig. B.8 Example of Excessive Lateral Displacement of Head

B.2.1.3 Frontal chest protection

B.2.1.3.1 Excessive vertical movement of the steering wheel (1 defect) means that the center of the steering wheel moves vertically (in Z direction) for more than 10 cm.

B.2.1.3.2 Excessive lateral movement of the steering wheel (1 defect) means that the center of the steering wheel moves laterally (in Y direction) for more than 15 cm.

B.2.1.4 Passenger protection and others

B.2.1.4.1 Passenger at risk of burn (1 defect) means that ATD body parts or clothes are melted or burned by the hot gas generated by airbag detonation.

B.2.1.4.2 Flying out of interior trim panels/hard components from the vehicle (1 defect) means that interior trim panels with sharp edges and corners (with a radius of curvature less than 2.5 mm) or hard components fly out from the vehicle and hit the ATD's face with a risk of injury during the crash.

B.2.1.4.3 Failure to unlock the seat belt or excessive unlocking force (1 defect) means that the seat belt cannot be unlocked or the unlocking force of the seat belt buckle is greater than 60 N to release the ATD from the restraint system after the crash.

B.2.1.4.4 Seat instability (1 defect) means that the seat adjustment and the part related to the passenger position are affected by the deformation of the vehicle floor or the seat lifting structure (for example, the relative vertical displacement between two seat fixing points is ≥ 6 cm, or some other deformation causes the seat cushion assembly to move outward and/or forward). However, this defect can be determined only when the seat cushion frame moves outward and/or forward to the extent that it has a negative impact on the ATD motion and directly causes the ATD to move forward or outward excessively.

B.2.1.4.5 Seat fixation failure (restraint system and ATD motion rated as "Poor") means that the seat fixing point is broken or the sliding rail is obviously displaced.

B.2.1.4.6 If the door is opened or separated, the restraint system and ATD motion is rated as "Poor".

Table B.1 Restraint System and ATD Motion Defects (Driver-side ATD)

Frontal head protection	
Stable frontal airbag action	0 defects
Partial frontal airbag action	1 defect
Little frontal airbag action	2 defects
The head "bottoms out" on the airbag	1 defect
Excessive lateral displacement of steering wheel (>10 cm)	1 defect
Two or more hard contacts on the head	1 defect
Frontal airbag not deployed or not deployed in time	Restraint system and ATD motion rated as "Poor"
Frontal chest protection	
Excessive vertical movement of steering wheel (>10 cm)	1 defect
Excessive lateral movement of steering wheel (>15 cm)	1 defect
Passenger protection and others	
Passenger at risk of burn	1 defect

Flying out of interior trim panels/hard components from the vehicle	1 defect
Failure to unlock the seat belt or excessive unlocking force	1 defect
Seat instability	1 defect
Seat fixation failure	Restraint system and ATD motion rated as "Poor"
Door opened or separated	Restraint system and ATD motion rated as "Poor"
Restraint system and ATD motion rating	
Good	0-1 defect
Acceptable	2-3 defects
Marginal	4-5 defects
Poor	6+ defects

Table B.2 Restraint System and ATD Motion Defects (Front Passenger-side ATD)

Frontal head protection	
Stable frontal airbag action	0 defects
Partial frontal airbag action	2 defects
Little frontal airbag action	4 defects
The head "bottoms out" on the airbag	1 defect
Two or more hard contacts on the head	1 defect
Frontal airbag not deployed or not deployed in time	Restraint system and ATD motion rated as "Poor"
Side head protection	
Adequate front coverage after deployment of the side head protection airbag	0 defects
Limited front coverage after deployment of the side head protection airbag	1 defect
Side head protection airbag not deployed	2 defects
Excessive lateral displacement of head	1 defect
Passenger protection and others	
Passenger at risk of burn	1 defect
Flying out of interior trim panels/hard components from the vehicle	1 defect
Failure to unlock the seat belt or excessive unlocking force	1 defect
Seat instability	1 defect
Seat fixation failure	Restraint system and ATD motion rated as "Poor"
Door opened or separated	Restraint system and ATD motion rated as "Poor"
Restraint system and ATD motion rating	
Good	0-1 defect
Acceptable	2-3 defects
Marginal	4-5 defects
Poor	6+ defects

B.2.2 Rear passenger restraint system and ATD motion rating

B.2.2.1 Head protection

B.2.2.1.1 Adequate side head protection (0 defects) means that the side head protection airbag effectively protects the head.

B.2.2.1.2 Limited side head protection (1 defect) means that the side head protection airbag does not effectively protect the head (for example, the rear ATD's head is stuck at the bottom of the side head protection airbag during a crash, or part of the ATD's head moves beyond the height of the door window frame).

B.2.2.1.3 Side head protection airbag not deployed (2 defects) means that the side head protection airbag is not equipped or not deployed, or fails to provide side head protection after deployment. For example, the rear ATD's head slides out of the coverage of the side head protection airbag during a crash.

B.2.2.1.4 Hard contact of head (1 defect) means the contact between head and door interior trim or B-pillar interior trim, etc. with a resultant acceleration exceeding 70 g.

B.2.2.1.5 Excessive lateral displacement of head (1 defect) means that more than half of the head moves to the outside of the contour of the rear passenger side window before deformation during the crash.

B.2.2.2 Passenger protection and others

B.2.2.2.1 Excessive forward leaning of passenger (1 defect) means that the rear ATD's head comes into contact with the front seat.

B.2.2.2.2 Flying out of interior trim panels/hard components from the vehicle (1 defect) means that interior trim panels with sharp edges and corners (with a radius of curvature less than 2.5 mm) or hard components fly out from the vehicle and hit the ATD's face with a risk of injury during the crash.

B.2.2.2.3 Failure to unlock the seat belt or excessive unlocking force (1 defect) means that the seat belt cannot be unlocked or the unlocking force of the seat belt buckle is greater than 60 N to release the ATD from the restraint system after the crash.

B.2.2.2.4 ATD submarining means the sudden drop of the force on iliac bone on either the left or the right side of the ATD within 1 ms, which can be confirmed by a high-speed camera.

B.2.2.2.5 Seat instability (1 defect) means that the seat adjustment and the part related to the passenger position are affected by the deformation of the vehicle floor or the seat lifting structure (for example, the relative vertical displacement between two seat fixing points is ≥ 6 cm, or some other deformation causes the seat cushion assembly to move outward and/or forward). However, this defect can be determined only when the seat cushion frame moves outward and/or forward to the extent that it has a negative impact on the ATD motion and directly causes the ATD to move forward or outward excessively.

B.2.2.2.6 Seat fixing point failure (restraint system and ATD motion rated as "Poor") means that the seat fixing point is broken or the sliding rail is obviously displaced.

B.2.2.2.7 If the door is opened or separated, the restraint system and ATD motion is rated as

"Poor".

Table B.3 Restraint System and ATD Motion Defects (Rear Passenger ATD)

Head protection	
Adequate side head protection	0 defects
Limited side head protection	1 defect
Side head protection airbag not deployed	2 defects
Head protection	
Hard contact of head	1 defect
Excessive lateral displacement of head	1 defect
Passenger protection and others	
Excessive forward leaning of passenger	1 defect
Flying out of interior trim panels/hard components from the vehicle	1 defect
Failure to unlock the seat belt or excessive unlocking force	1 defect
ATD submarining	Restraint system and ATD motion rating downgraded by one level
Seat instability	1 defect
Seat fixation failure	Restraint system and ATD motion rated as "Poor"
Door opened or separated	Restraint system and ATD motion rated as "Poor"
Overall Rating of Restraint System and ATD Motion	
Good	0 defects
Acceptable	1 defect
Marginal	2-3 defects
Poor	4+ defects

B.3 ATD injury rating

B.3.1 Front passenger injury rating

Rate the ATD injury with the measured injury values of the Hybrid III 50th ATD. See Table B.4 for ATD measurement parameters and filtering level.

Table B.4 ATD Measurement Parameters and Filtering Level

Measuring Parts	Measurement Parameters	Filtering Level
Head	Acceleration Ax, Ay, Az	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Neck	Force Fx, Fy, Fz	CFC 1000
	Moment My	CFC 600
Chest	Acceleration Ax, Ay, Az	CFC 180
	Compression deformation D	CFC 600
Thigh and hip	Compression force on thigh (left/right) Fz	CFC 600
	Sliding displacement of knee joint (left/right) D	CFC 180
Tibia	Force on upper tibia and moment (left/right) F_z, M_x, M_y	CFC 600
	Force on lower tibia and moment (left/right) F_z, M_x, M_y	CFC 600
Foot	Acceleration (left/right) Ax, Az	CFC 180

The ATD injury rating involves four parts: head and neck, chest, thigh and hip, tibia and

foot.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part. Thigh/hip and tibia/foot are rated according to the lower rating of the left or right side. Table B.6 shows the limit range of rating indexes of four levels: good, acceptable, marginal and poor.

B.3.1.1 Head and neck

Head rating indexes: HIC_{15}, HIC_{36} (for reference but not for rating), cumulative 3 ms resultant acceleration (for reference but not for rating), and maximum resultant head acceleration.

If the peak resultant head acceleration exceeds 70 g because the ATD's head comes into contact with any hard object of the vehicle, the head and neck injury rating will be degraded by one level. See Fig. B.9 for details of head and neck injuries in multiple crashes.

Neck rating indexes: N_{ij}, axial tensile force Fz, axial compressive force Fz, shear force Fx, compressive bending moment My (for reference but not for rating), and tensile bending moment My (for reference but not for rating).

If the curves of duration vs. axial tensile force Fz, axial compressive force Fz and shear force Fx on the neck go beyond the limits of "good" shown in Figs. B.10, B.11 and B.12, head and neck rating "good" will be degraded to "acceptable".

Head calculation:

$$HIC = (t_2 - t_1)\left[\frac{\int_{t_1}^{t_2} A_R.dt}{(t_2 - t_1)}\right]^{2.5}$$

$$A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Where, *Ax*, *Ay* and *Az* are acceleration values of the head in three directions, in g.

t_2-t_1≤15 ms (for rating), t_2-t_1≤36 ms (for reference).

Neck calculation:

$$N_{ij} = (F_z/F_{zc}) + \left(M_{OCy}/M_{yc}\right)$$

$$M_{OCy} = M_y - (D \bullet F_x)$$

Where, *Fz* is the axial force on neck, in N;

Fzc is the critical axial force on neck, in N;

Fx is the shear force on neck, in N;

My is the tensile/compressive bending moment of neck, in Nm;

Myc is the critical tensile/compressive bending moment of neck, in Nm;

D (0.01778), in m, is the distance between the center of the neck force sensor and the center of the head-neck connecting shaft.

Table B.5 Critical Values for N_{ij} Calculation

ATD Type	*Fzc* - axial tensile force	*Fzc* - axial compressive force	*Myc* - compressive bending moment	*Myc* - tensile bending moment
Hybrid III 50th	6806N	-6160N	310Nm	-135Nm

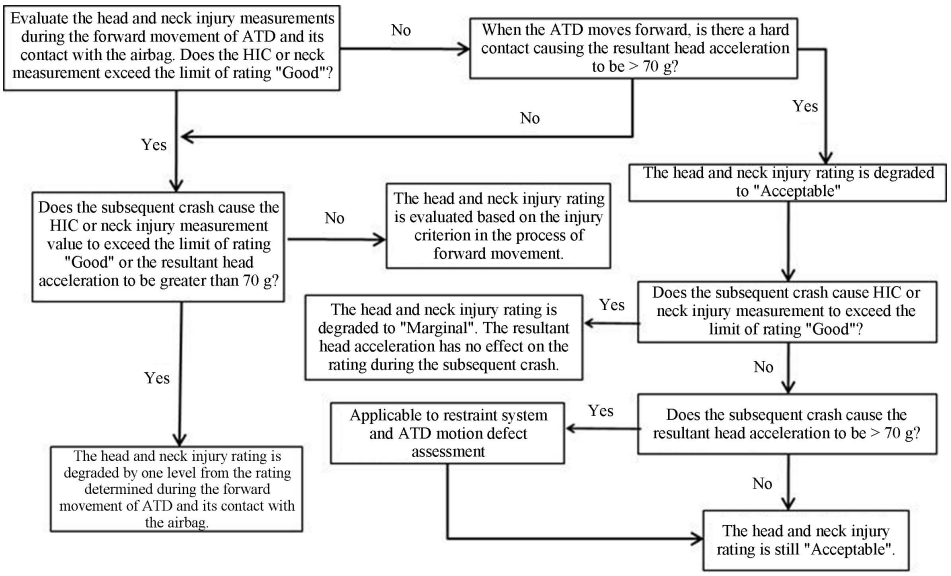


Fig. B.9 Flow Chart of Head and Neck Injury Rating in Multiple Crashes

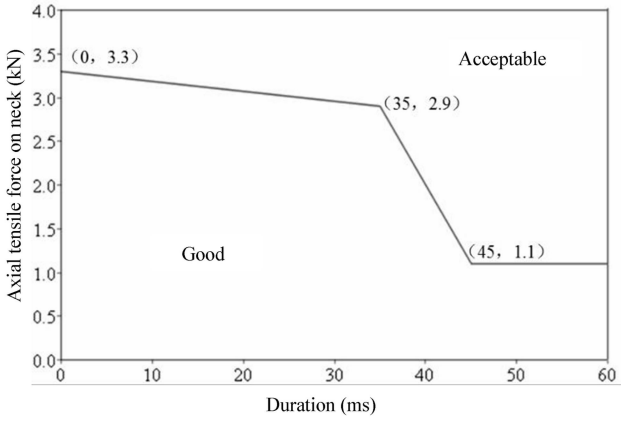


Fig. B.10 Curve of Duration vs. Tensile Force on Neck Fz

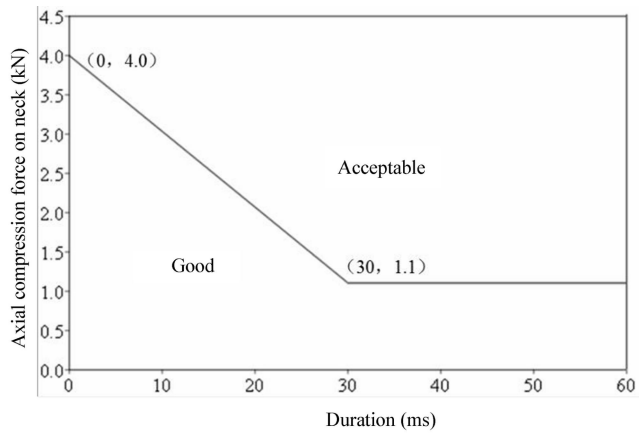


Fig. B.11 Curve of Duration vs. Compressive Force on Neck Fz

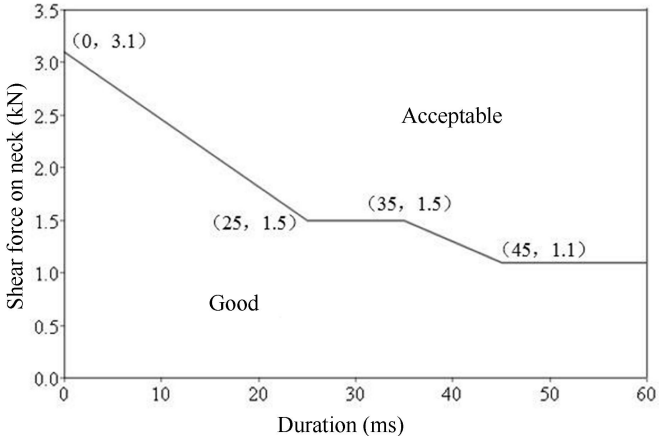


Fig. B.12 Curve of Duration vs. Shear Force on Neck Fx

B.3.1.2 Chest

Chest rating indexes: continuous acceleration A_3 ms, compression deformation D, compression velocity V, and viscous criterion VC.

VC calculation:

$$(VC)_t = 1.3V_t \times C_t$$

$$C_t = \frac{D_t}{0.229}$$

The chest compression velocity at time point t is calculated from the filtered compression deformation (filtering level CFC60).

$$V_t = \frac{8\left[D_{(t+1)} - D_{(t-1)}\right] - \left[D_{(t+2)} - D_{(t-2)}\right]}{12\delta t}$$

Where, Dt is the deformation at time point t, in m; δt is the time interval for compression deformation measurement, in s.

B.3.1.3 Thigh and hip

Thigh and hip rating indexes: knee-thigh-hip (KTH) injury risk, compressive force Fz on thigh (for reference but not for rating).

KTH injury risk is determined according to Fig. B.14 based on the compressive force and impulse value of each thigh. The impulse value is obtained by integrating the force on thigh from the beginning of thigh compression to 4050 N after the peak force is reached; as shown in Fig. B.13.

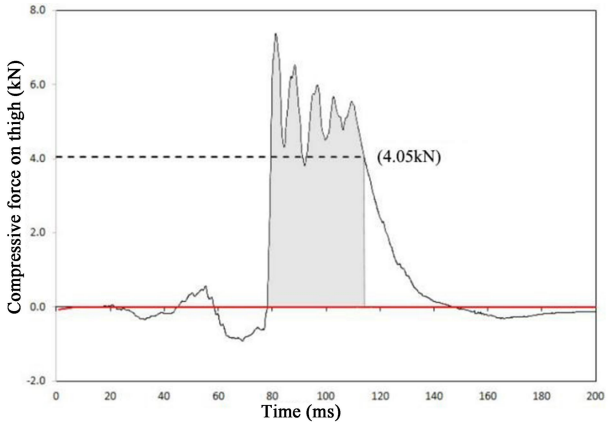


Fig. B.13 Thigh Impulse on Hybrid III 50th ATD

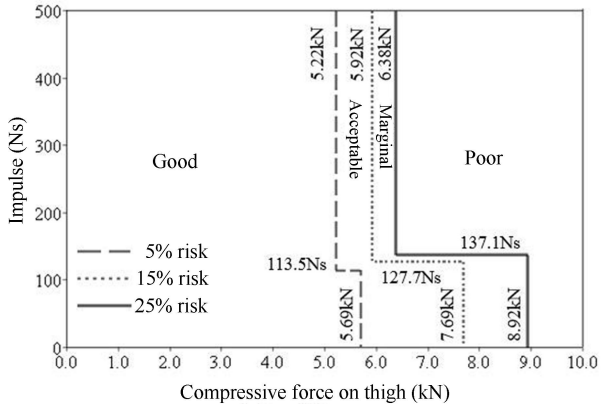


Fig. B.14 KTH Injury Risk

B.3.1.4 Tibia and foot

Tibia rating indexes: axial compressive force on upper tibia and lower tibia Fz, knee joint sliding displacement D, and tibia index TI.

Tibia index TI is calculated with the adjusted bending moment My.

MY upper adjustment = MY upper measured value - [(FZ tibia) (0.02832)]

MY lower adjustment =MY lower measured value + [(FZ tibia) (0.006398)]

Note: The bending moment is measured in Nm, and the force in N.

TI calculation:

$$M_R = \sqrt{(M_X)^2 + \left(M_{Y\,\text{adjustment}}\right)^2}$$

$$\text{TI} = |M_R/(M_C)_R| + |F_Z/(F_C)_z|$$

Where, M_X is the bending moment around X axis, M_Y adjustment is the adjusted bending moment around Y axis, $(M_C)_R$ is critical bending moment, F_Z is axial compressive force in Z direction, and $(F_C)_Z$ is critical compressive force in Z direction.

Foot rating index: maximum resultant foot acceleration.

Table B.6 ATD Injury Rating

Body Parts	Parameters	Good	Acceptable	Marginal	Poor
Head and neck	HIC_{15}	≤560	≤700	≤840	>840
	N_{ij}	≤0.80	≤1.00	≤1.20	>1.20
	Tensile force F_Z (kN)*	≤2.6	≤3.3	≤4.0	>4.0
	Compressive force F_Z (kN)*	≤3.2	≤4.0	≤4.8	>4.8
Chest	Acceleration A_3 ms (g)	≤60	≤75	≤90	>90
	Compression deformation D (mm)	≤50	≤60	≤75	>75
	Compression velocity V (m/s)	≤6.6	≤8.2	≤9.8	>9.8
	Viscous criterion VC (m/s)	≤0.8	≤1.0	≤1.2	>1.2
Thigh and hip	KTH Injury Risk	≤5%	≤15%	≤25%	>25%
Tibia and foot	Knee joint sliding displacement D (mm)	≤12	≤15	≤18	>18
	Tibia index (upper and lower), TI	≤0.80	≤1.00	≤1.20	>1.20
	Axial force on tibia F_Z (kN)	≤4.0	≤6.0	≤8.0	>8.0
	Maximum resultant foot acceleration (Ag)	≤150	≤200	≤260	>260

* See Fig. B.10 and Fig. B.11 for curves of duration vs. axial force on neck.

B.3.2 Rear passenger injury rating

Rate the ATD injury with the measured injury values of the Hybrid III 5th ATD. See Table B.7 for ATD measurement parameters and filtering level.

Table B.7 ATD Measurement Parameters and Filtering Level

Measuring Parts	Measurement Parameters	Filtering Level
Head	Acceleration Ax, Ay, Az	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Neck	Force Fx, Fy, Fz	CFC 1000
	Moment My	CFC 600
Chest	Acceleration Ax, Ay, Az	CFC 180
	Compression deformation D	CFC 600
Thigh and hip	Compression force on thigh (left/right) Fz	CFC 600
	Sliding displacement of knee joint (left/right) D	CFC 180
	Force on iliac bone (left/right) Fx	CFC 180
Thigh and hip	Force on lumbar spine	CFC 600
	Pelvic acceleration Ax, Az	CFC 1000

The injury rating of ATD involves three parts: head and neck, chest, and thigh and hip.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part. Thigh/hip is rated according to the lower rating on the left or right side. Table B.8 shows the limit range of rating indexes of four levels: good, acceptable, marginal and poor.

B.3.2.1 Head and neck

Head rating indexes: HIC_{15}, cumulative 3 ms resultant acceleration.

Head HIC is also calculated with the Hybrid III 50th ATD.

Neck rating indexes: shear force Fx, axial tensile force Fz and tensile bending moment My.

If the peak resultant head acceleration exceeds 70 g due to hard contact between head and vehicle, the head and neck injury rating will be degraded by one level.

B.3.2.2 Chest

Chest rating indexes: compression deformation D, and viscous criterion VC.

The viscous criterion VC is also calculated with Hybrid III 50th ATD, and Ct calculation formula is as follows:

$$C_t = \frac{D_t}{0.187}$$

B.3.2.3 Thigh and hip

Thigh and hip rating indexes: compressive force on left and right thighs Fz, force on left and right iliac bones (reference value), and knee joint sliding displacement D (reference value).

Table B.8 ATD Injury Rating

Body Parts	Parameters	Good	Acceptable	Marginal	Poor
Head and neck	HIC_{15}	≤560	≤700	≤840	>840
	Acceleration A_3 ms (g)	≤72	≤76	≤80	>80
	Shear force Fx (kN)	≤1.20	≤1.58	≤1.95	>1.95
	Tensile force Fz (kN)	≤2.10	≤2.62	≤3.14	>3.14
	Tensile bending moment My (Nm)	≤36	≤43	≤49	>49
Chest	Compression deformation D (mm)	≤41.0	≤49.2	≤61.5	>61.5
	Viscous criterion VC (m/s)	≤0.8	≤1.0	≤1.2	>1.2
Thigh and hip	Compressive force Fz (kN)	≤5.0	≤6.2	≤7.4	>7.4

B.4 Vehicle Structure Rating

B.4.1 Rating by intrusion measurement

The vehicle structure is rated by intrusion measurement (see Fig. B.15), and the rating is corrected (degraded) according to the qualitative observation result of the structural integrity of the passenger compartment.

Measuring points are distributed in two areas: the lower part and the upper part of the passenger compartment. The lower part includes the A-pillar lower hinge, right footrest, right toepan, center toepan and rocker panel. The upper part includes the center instrument panel, A-pillar upper hinge, upper instrument panel and lower right instrument panel.

Compare the X-Y-Z resultant displacement of A-pillar lower hinge, right footrest, right toepan, center toepan, center instrument panel, A-pillar upper hinge, upper instrument panel and lower right instrument panel with the rating reference values (see Fig. B.15). For each measuring point, if it moves forward along X axis (away from the passenger seat), only the Y-Z resultant displacement is compared with the rating reference value. For the A-pillar upper hinge and A-pillar lower hinge, if the measuring point moves rightward (outward) along Y axis, only the X-Z resultant displacement is compared with the rating reference value. For the rating of A-pillar upper hinge and A-pillar lower hinge, take the maximum resultant displacement of three positions respectively. For the rocker panel, only the inward Y-direction displacement is compared with the rating reference value, and the Y-direction displacement is the average value of three positions on the rocker panel.

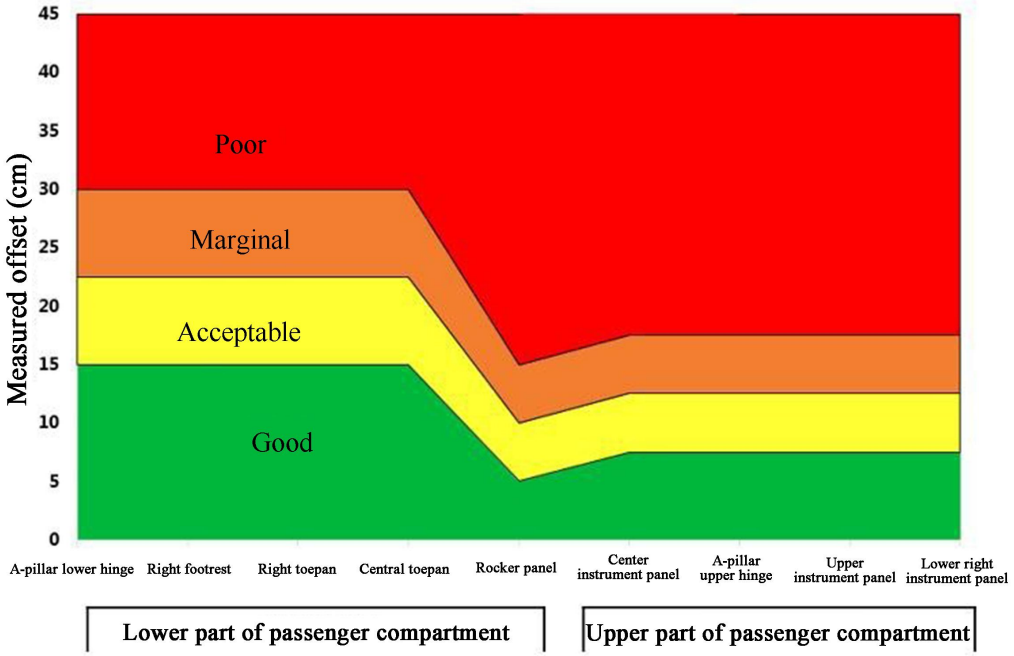


Fig. B.15 Passenger Compartment Intrusion Rating

The lower part and upper part of the passenger compartment are rated separately. If the rating is not degraded according to qualitative observation result, the overall structure rating is the lower rating of the lower and upper parts of the passenger compartment.

For the lower part or the upper part of the passenger compartment: If the intrusion measurement falls within different rating ranges, the structure rating is the rating for the area

with the most measured values, but it shall not be more than one level higher than the rating for the area with the worst measured value. If half of the measurement results are in the area of the same rating, while the other half in the area of another rating, the structure rating is the lower rating. The higher rating is taken if the intrusion lies on the boundary of two different ratings.

The structure measuring points at the upper and lower parts of the passenger compartment are rated according to the thresholds of rating indexes. See Table B.9 for specific rating requirements:

Table B.9 Vehicle Structure Rating

Rating Object		Evaluation Index	Good	Acceptable	Marginal	Poor
Lower part of passenger compartment	A-pillar lower hinge	Resultant displacement (cm)	≤15	≤22.5	≤30	>30
	Right footrest					
	Right toepan					
	Central toepan					
	Rocker panel	Y-direction intrusion (cm)	≤5	≤10	≤15	>15
Upper part of passenger compartment	Center instrument panel	Resultant displacement (cm)	≤7.5	≤12.5	≤17.5	>17.5
	A-pillar upper hinge					
	Upper instrument panel					
	Lower right instrument panel					

B.4.2 Qualitative observation of vehicle structure rating

If the ATD's feet are stuck and can only be taken out with tools, the hinge pillar is completely torn, and the front wall is torn in a large area (for example, the tearing length is greater than 20 cm, and the width is greater than 5 cm), the vehicle structure rating shall be degraded by one level from the rating of intrusion measurement.

B.4.3 Integrity of fuel system and high voltage system

If there is obvious fuel leakage or damage to the high voltage system (e.g., electric drive system) during the test, the vehicle structure rating and overall rating will be downgraded to "Poor".

Obvious fuel leakage means that more than 28 g of fuel leaks from crash to vehicle standstill, and more than 142 g leaks in the following 5 min, and 28 g leaks per minute in the next 25 min.

The high voltage system must meet the requirements for electrolyte leakage, REESS safety, and electric shock protection in GB/T 31498-2021 *Post Crash Safety Requirement for Electric Vehicle*, so as to avoid level degrading. The specific requirements are summarized as follows:

- Requirements for electrolyte leakage

  Within 30 min after the crash, there shall be no electrolyte overflowing from the REESS to the passenger compartment and no over 5.0 L of electrolyte overflowing from the REESS.

- Requirements for REESS safety

① The REESS located in the passenger compartment shall remain in the installation position, REESS components shall be kept within the housing, and any part of the REESS located outside the passenger compartment shall not enter the passenger compartment.

② Within 30 min after the end of crash, the REESS shall not explode or catch fire.

- Requirements for electric shock protection

Electric shock protection involves four rating indexes: voltage, electric energy, physical protection and insulation resistance requirements. Each high voltage bus shall meet at least one of the four rating indexes. If the crash test is carried out with the REESS of the vehicle actively disconnected from the balance of electric power system, the balance of electric power system of the vehicle shall meet the requirements for physical protection or insulation resistance; the REESS and high voltage bus for charging shall meet one of the four rating indexes:

① Voltage requirements

The voltages V_b, V_1 and V_2 of high voltage bus measured according to GB/T 31498-2021 *Post Crash Safety Requirement for Electric Vehicle* shall not exceed 30 V AC or 60 V DC.

② Electric energy requirements

Both the total electric energy TE on the high voltage bus and the energy (TEy1, TEy2) stored in Y-capacitor shall be less than 0.2 J.

③ Physical protection

To prevent direct contact with high-voltage live parts, the vehicle shall have IPXXB protection after the crash; to prevent electric shock injury caused by indirect contact, the resistance between all exposed conductive parts and electric chassis shall be less than 0.1 Ω as measured with a current higher than 0.2 A. This requirement is deemed to be met when the electrical connection is made by welding.

④ Insulation resistance

If the AC high voltage bus and the DC high voltage bus are subject to conductive insulation with each other, the insulation resistance between the DC high voltage bus and the electric chassis shall be greater than or equal to 100 Ω/V, and the insulation resistance between the AC high voltage bus and the electric chassis shall be greater than or equal to 500 Ω/V.

If the AC high voltage bus and the DC high voltage bus are conductively connected with each other, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 500 Ω/V. After the crash, if the IP rating of all AC high voltage buses reaches IPXXB or the AC voltage is equal to or less than 30 V, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 100 Ω/V.

B.5 Overall rating

The overall rating is calculated according to Table B.10 based on the vehicle structure, the measured injuries of the heads and necks, chests, thighs and hips, and tibias and feet of the driver and front passenger and of the heads and necks, chests, thighs and hips of the rear passengers, and the front and rear restraint system and ATD motion.

Table B.10 Overall Rating

Rating Item	Level			
	Good (G)	Acceptable (A)	Marginal (M)	Poor (P)
Vehicle structure	0	2	6	10
Driver				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Tibia and foot	0	1	2	4
Restraint system and ATD motion	0	2	6	10
Front passenger				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Tibia and foot	0	1	2	4
Restraint system and ATD motion	0	2	6	10
Rear passengers				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Restraint system and ATD motion	0	2	6	10
Overall rating limit	0-3	4-9	10-19	20+

Note: If two doors in the same row cannot be opened from outside normally without tools after the test, the overall rating will be degraded by one level.

Annex C

Rating Method for Moderate Overlap Frontal Crash

C.1 Introduction

The moderate overlap frontal crash rating includes three aspects: restraint system and ATD motion, ATD injury, and vehicle structure and compatibility. This protocol elaborates on the rating methods.

C.2 Restraint system and ATD motion rating

C.2.1 Front passenger restraint system and ATD motion rating

C.2.1.1 Head and neck protection

C.2.1.1.1 Unstable contact with frontal airbag (1 defect, as shown in Fig. C.1) means that the ATD moves forward and comes into contact with the deployed airbag, but the center of gravity of the ATD's head is outside the outer edge of the airbag, and other situations that may affect the head protection performance of the airbag, such as the steering wheel detaching from the steering column and the head "bottoming out" on the frontal airbag.

During the deep contact between the ATD's head and the airbag, if there is one or more obvious rising edges in the head acceleration curve, the starting point and the end point causing an obvious local peak value are linearly smoothed. If the local peak value is more than 5 g higher than the smoothed value for more than 3 ms, it is considered that the head "bottoms out" on the frontal airbag.

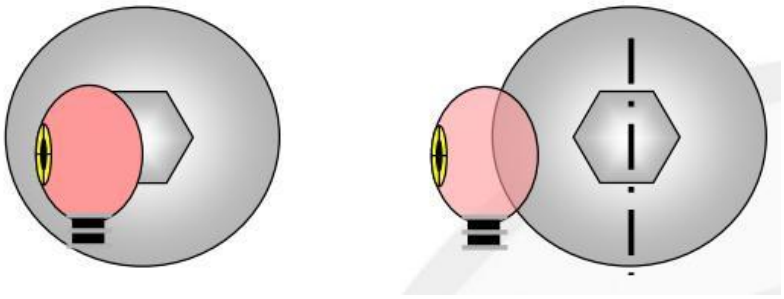


Fig. C.1 Unstable Contact with Frontal Airbag (Right)

C.2.1.1.2 Dangerous deployment of frontal airbag (1 defect, as shown in Fig. C.2) means that the airbag sweeps the ATD's face horizontally or vertically in the head rating area during deployment, causing potential risks to the ATD's face or eyes, or its deployment rate is greater than 90 m/s. The head rating area is the backward area 150 mm in front of the ATD's face and perpendicular to the longitudinal plane of the vehicle in the test state.

Fig. C.2 Example of Dangerous Deployment of Frontal Airbag

C.2.1.1.3 Excessive movement of steering wheel (1 defect) means that the center of the steering wheel moves more than 10 cm laterally, longitudinally or vertically.

C.2.1.1.4 Two or more hard contacts on the head (1 defect) mean two or more hard contacts resulting in a resultant head acceleration exceeding 70 g.

If there is one hard contact resulting in the resultant head acceleration exceeding 70 g, the head and neck injury rating will be degraded by one level, but the defects in the restraint system and ATD motion rating will not be counted.

C.2.1.1.5 If the frontal airbag is not deployed or not deployed in time, the restraint system and ATD motion is rated as "Poor".

C.2.1.2 Chest and abdomen protection

C.2.1.2.1 Obvious contact between the steering wheel and the chest (1 defect) means that the steering wheel is obviously directly loaded on the ATD's chest.

C.2.1.2.2 Excessive shoulder belt load (2 defects) means that the peak shoulder belt force (CFC60 filter) exceeds 6 kN.

C.2.1.3 Knee and pelvis protection

C.2.1.3.1 Risk of concentrated loads in the knee rating area (1 defect) means that there are parts in the knee rating area that may cause abnormal increase in compressive force on thigh or knee slip, such as ignition switch, adjustment button, glove box lock catch, structural mounting bracket and other hard parts. In the MPDB crash test, this defect cannot be exempted if one of the following conditions occurs to the vehicle:

a) Force load on thigh of the driver or front passenger greater than 3.8 kN;

b) Frontal airbag not deployed or not deployed in time;

c) Footrest tearing;

d) Damage to the structural integrity of passenger compartment.

This defect can be exempted if the risk is proved to be low by knee mapping test at the location with concentrated load risk, or if there is continuous flexible foam wrapping with a thickness of more than 10 mm.

The knee rating area is defined as the lower instrument coverage area 50 mm upward and downward and 20 mm inward respectively from the uppermost edges of the crash marks on the ATD's left and right knees after the test.

C.2.1.3.2 ATD submarining (2 defects) means that the reduction rate of either of the two forces on iliac bone of the ATD increases sharply for 1 ms, and it is confirmed by high-speed camera that the ATD has obvious submarining.

C.2.1.4 Leg and foot protection

C.2.1.4.1 Footrest tearing (1 defect) means that the footrest space is torn due to the failure of welding spots, resulting in unstable foot space in the footrest area, serious damage to the firewall, contact of feet with sheet metal with sharp edges, etc.

C.2.1.4.2 Excessive pedal displacement (1 defect) means that the pedal displacement is greater than 15 cm backward or 8 cm upward. This defect can be exempted if the pedal is designed to fall off in case of crash and is completely detached from its fixing point during the crash without significant resistance to movement.

C.2.1.5 Passenger protection and others

C.2.1.5.1 Passenger at risk of burn (1 defect) means that ATD body parts or clothes are melted or burned by the hot gas generated by airbag detonation.

C.2.1.5.2 Damage to the structural integrity of passenger compartment (1 defect) means that the vehicle structure shows any of the following conditions after the crash:

1) Door latch or hinge failure, unless the door is adequately retained by the door frame;

2) Buckling or other failures of the door resulting in severe loss of frontward and backward compressive strength;

3) Separation or near separation of the instrument panel frame from A-pillar joint;

4) Severe loss of strength of the door frame.

C.2.1.5.3 Failure to unlock the seat belt or excessive unlocking force (1 defect) means that the seat belt cannot be unlocked or the unlocking force of the seat belt buckle is greater than 60 N to release the ATD from the restraint system after the crash.

C.2.1.5.4 Seat instability (1 defect) means that the seat adjustment and the part related to the passenger position are affected by the deformation of the vehicle floor or the seat lifting structure (for example, the relative vertical displacement between two seat fixing points is ≥ 6 cm, or some other deformation causes the seat cushion assembly to move outward or forward). However, this defect can be determined only when the seat cushion frame moves outward or forward to the extent that it has a negative impact on the ATD motion and directly causes the ATD to move forward or outward excessively.

C.2.1.5.5 Seat fixation failure (restraint system and ATD motion rated as "Poor") means that the seat fixing point is broken or the sliding rail is obviously displaced.

C.2.1.5.6 If the door is opened or separated, the restraint system and ATD motion is rated as "Poor".

Table C.1 Restraint System and ATD Motion Defects (Driver)

Head and neck protection	
Unstable contact with frontal airbag	1 defect
Dangerous deployment of frontal airbag	1 defect
Excessive displacement of steering wheel (> 10 cm laterally, longitudinally or vertically)	1 defect
Two or more hard contacts on the head	1 defect
Frontal airbag not deployed or not deployed in time	Restraint system and ATD motion rated as "Poor"
Chest and abdomen protection	
Obvious contact between steering wheel and chest	1 defect
Excessive shoulder belt load	2 defects
Knee and pelvis protection	
Risk of concentrated loads in the knee rating area	1 defect
ATD submarining	2 defects
Leg and foot protection	
Footrest tearing	1 defect
Excessive pedal displacement	1 defect
Passenger protection and others	
Passenger at risk of burn	1 defect
Damage to the structural integrity of passenger compartment	1 defect
Failure to unlock the seat belt or excessive unlocking force	1 defect
Seat instability	1 defect
Seat fixation failure	Restraint system and ATD motion rated as "Poor"
Door opened or separated	Restraint system and ATD motion rated as "Poor"
Restraint system and ATD motion rating	
Good	0-1 defect
Acceptable	2-3 defects
Marginal	4-5 defects
Poor	6+ defects

Table C.2 Restraint System and ATD Motion Defects (Front Passenger)

Head and neck protection	
Unstable contact with frontal airbag	1 defect
Dangerous deployment of frontal airbag	1 defect
Two or more hard contacts on the head	1 defect
Frontal airbag not deployed or not deployed in time	Restraint system and ATD motion rated as "Poor"
Chest and abdomen protection	
Excessive shoulder belt load	2 defects
Knee and pelvis protection	
Risk of concentrated loads in the knee rating area	1 defect
Leg and foot protection	
Footrest tearing	1 defect
Passenger protection and others	

Passenger at risk of burn	1 defect
Damage to the structural integrity of passenger compartment	1 defect
Failure to unlock the seat belt or excessive unlocking force	1 defect
Seat instability	1 defect
Seat fixation failure	Restraint system and ATD motion rated as "Poor"
Door opened or separated	Restraint system and ATD motion rated as "Poor"
Restraint system and ATD motion rating	
Good	0-1 defect
Acceptable	2-3 defects
Marginal	4-5 defects
Poor	6+ defects

C.3 ATD injury rating

C.3.1 Driver injury rating

Rate the ATD injury with the measured injury values of the THOR 50th ATD. See the table for ATD measurement parameters and filtering level.

Table C.3 ATD Measurement Parameters and Filtering Level

Measuring Parts	Measurement Parameters	Filtering Level
Head	Acceleration Ax, Ay, Az	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Neck	Force Fx, Fy, Fz	CFC 1000
	Moment My	CFC 600
Chest	Compression deformation R_{max}	CFC 180
Abdomen	Compression deformation D_{max}	CFC 180
Thigh and hip	Compression force on thigh (left/right) Fz	CFC 600
	Resultant force on pelvis (left/right) F_{AR}	CFC 600
Tibia	Sliding displacement of knee joint (left/right) D	CFC 180
	Force on upper tibia and moment (left/right) F_z, M_x, M_y	CFC 600
	Force on lower tibia and moment (left/right) F_z, M_x, M_y	CFC 600
Foot	Acceleration (left/right) Ax, Az	CFC 180

The ATD injury rating involves four parts: head and neck, chest and abdomen, thigh and hip, tibia and foot.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part. Thigh/pelvis and tibia/foot are rated according to the lower rating of the left or right side. The table shows the limit range of rating indexes of four levels: good, acceptable, marginal and poor.

C.3.1.1 Head and neck

Head rating indexes: HIC_{15}, HIC_{36} (for reference but not for rating), cumulative 3 ms resultant acceleration (for reference but not for rating), and maximum resultant head acceleration.

If the peak resultant head acceleration exceeds 70 g due to hard contact between head and vehicle, the head and neck injury rating will be degraded by one level (see Fig. C.3).

Neck rating indexes: shear force Fx, axial tensile force Fz, and tensile bending moment M_{OCy}.

Head calculation:

$$HIC = (t_2 - t_1)\left[\frac{\int_{t_1}^{t_2} A_R . dt}{(t_2 - t_1)}\right]^{2.5}$$

$$A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Where, *Ax*, *Ay* and *Az* are acceleration values of the head in three directions, in g.

t_2-t_1≤15 ms.

Neck calculation:

$$M_{OCy} = M_y$$

Where, *My* is the tensile/compressive bending moment of the neck, in Nm.

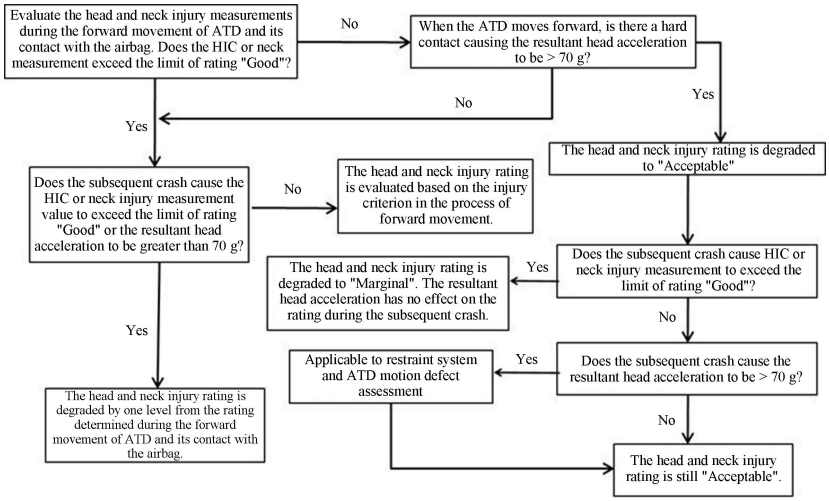


Fig. C.3 Flow Chart of Head and Neck Injury Rating in Multiple Crashes

C.3.1.2 Chest and abdomen

Chest rating index: peak resultant deformation R_{max}.

R_{max} calculation:

$$R_{max} = max(UL_{max}, UR_{max}, LL_{max}, LR_{max})$$

$$[U/L \mid R/L]_{max} = max(\sqrt{[L/R]X(t)^2_{[U/L]s} + [L/R]Y(t)^2_{[U/L]s} + [L/R]Z(t)^2_{[U/L]s}})$$

Where, $[U/L \mid R/L]_{max}$ is the peak resultant deformation of upper left chest, lower left chest, upper right chest and lower right chest, in mm;

$[L/R][X(t)/Y(t)/Z(t)]_{[U/L]s}$ is the time-history curve of deformation of upper left chest, lower left chest, upper right chest and lower right chest in the X, Y and Z directions in their respective local coordinate systems, in mm.

Abdomen rating index: peak deformation D_{max} of abdomen in X direction.

C.3.1.3 Thigh and pelvis

Thigh and pelvis rating indexes: compressive force on thigh F_z and resultant force on acetabulum F_{AR}.

The compressive force on thigh F_z is rated by a cumulative curve. The cumulative curve of compressive force on thigh can be obtained according to the time-history curve of compressive force on thigh, and then the rating can be determined according to the cumulative curve shown in Fig. C.4.

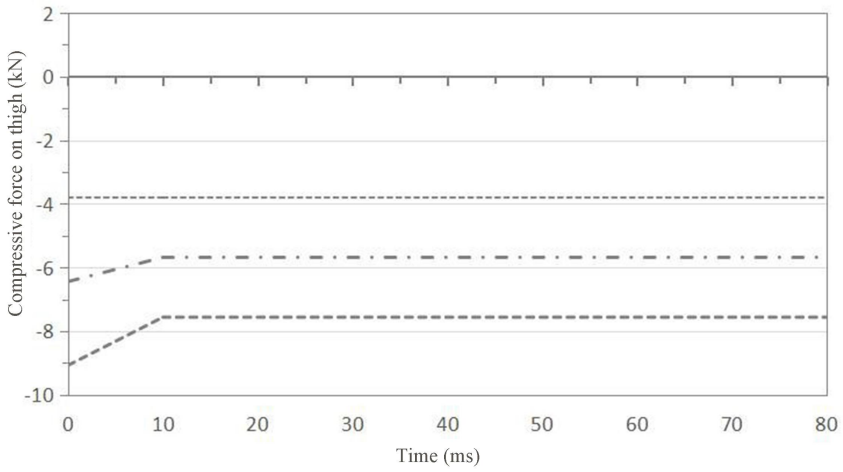


Fig. C.4 Cumulative Curve of Compressive Force on Thigh

Calculation of resultant force on acetabulum F_{AR}:

$$[F(t)_{[L/R]AR}]_{max} = max(\sqrt{F(t)^2{}_{[L/R]x} + F(t)^2{}_{[L/R]y} + F(t)^2{}_{[L/R]z}})$$

Where, $[F(t)_{[L/R]AR}]_{max}$ is the peak resultant force on the left and right acetabulums in compression (left Fx > 0, right Fx < 0), in kN;

$F(t)_{[L/R]x}$, $F(t)_{[L/R]y}$ and $F(t)_{[L/R]z}$ are the time-history curves of the left and right acetabular force sensors in X, Y and Z directions, in kN.

C.3.1.4 Tibia and foot

Tibia rating indexes: axial compressive force on upper tibia and lower tibia Fz, knee joint sliding displacement D, and tibia index TI.

Tibia index TI is calculated with the adjusted bending moment My.

$$M_{Y\ upper\ adjustment} = M_{Y\ upper\ measured\ value} - [(F_{Z\ tibia})\ (0.02832)]$$

$$M_{Y\ \text{lower adjustment}} = M_{Y\ \text{lower measured value}} + [(F_{Z\ \text{tibia}})\ (0.006398)]$$

Note: The bending moment is measured in Nm, and the force in N.

TI calculation:

$$M_R = \sqrt{(M_X)^2 + \left(M_{Y\ \text{adjustment}}\right)^2}$$

$$\text{TI} = |M_R/(M_C)_R| + |F_Z/(F_C)_z|$$

Where, M_X is the bending moment around X axis, M_Y adjustment is the adjusted bending moment around Y axis, $(M_C)_R$ is critical bending moment, F_Z is axial compressive force in Z direction, and $(F_C)_Z$ is critical compressive force in Z direction.

Foot rating index: maximum resultant foot acceleration.

Table C.4 ATD Injury Rating

Body Parts	Parameters	Good	Acceptable	Marginal	Poor
Head and neck	HIC_{15}	≤560	≤700	≤840	>840
	Shear force F_X (kN)	≤1.9	≤2.5	≤3.1	>3.1
	Tensile force F_Z (kN)	≤2.7	≤3.0	≤3.3	>3.3
	Tensile bending moment M_{ocy} (Nm)	≤42.0	≤49.5	≤57.0	>57.0
Chest and abdomen	Chest compression deformation R_{max} (mm)	≤42	≤50	≤62	>62
	Abdomen compression deformation D_{max} (mm)	≤88			>88
Thigh and pelvis	Compressive force on thigh F_Z (kN)	≤3.8@0ms ≤3.8@10ms	≤6.44@0ms ≤5.68@10ms	≤9.07@0ms ≤7.56@10ms	>9.07@0ms >7.56@10ms
	Compressive force on acetabulum, F_{AR} (kN)	≤3.28	≤3.69	≤4.10	>4.10
Tibia and foot	Knee joint sliding displacement D (mm)	≤12	≤15	≤18	>18
	Tibia index (upper and lower), TI	≤0.80	≤1.00	≤1.20	>1.20
	Axial force on tibia F_Z (kN)	≤4.0	≤6.0	≤8.0	>8.0
	Maximum resultant foot acceleration, A (g)	≤150	≤200	≤260	>260

C.3.2 Front passenger injury rating

Rate the ATD injury with the measured injury values of the Hybrid III 50th ATD. See Table C.5 for ATD measurement parameters and filtering level.

Table C.5 ATD Measurement Parameters and Filtering Level

Measuring Parts	Measurement Parameters	Filtering Level
Head	Acceleration A_x, A_y, A_z	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Neck	Force Fx, Fy, Fz	CFC 1000
	Moment M_y	CFC 600
Chest	Acceleration A_x, A_y, A_z	CFC 180
	Compression deformation D	CFC 600
Thigh and hip	Compression force on thigh (left/right) F_z	CFC 600
	Sliding displacement of knee joint (left/right) D	CFC 180
Tibia	Force on upper tibia and moment (left/right) F_z, M_x, M_y	CFC 600
	Force on lower tibia and moment (left/right) F_z, M_x, M_y	CFC 600
Foot	Acceleration (left/right) Ax, Az	CFC 180

The ATD injury rating involves four parts: head and neck, chest, thigh and hip, tibia and foot.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part. Thigh/hip and tibia/foot are rated according to the lower rating of the left or right side. The table shows the limit range of rating indexes of four levels: good, acceptable, marginal and poor.

C.3.2.1 Head and neck

Head rating indexes: HIC_{15}, HIC_{36} (for reference but not for rating), cumulative 3 ms resultant acceleration (for reference but not for rating), and maximum resultant head acceleration.

If the peak resultant head acceleration exceeds 70 g due to hard contact between head and vehicle, the head injury rating will be degraded by one level (see Fig. C.3).

Neck rating indexes: N_{ij}, axial tensile force Fz, axial compression Fz, and shear force Fx.

If the curves of duration vs. axial tensile force Fz, axial compressive force Fz and shear force Fx on the neck go beyond the limits of "good" shown in Figs. C.5 ~ C.7, head/neck rating "good" will be degraded to "acceptable".

Head calculation:

$$HIC = (t_2 - t_1)\left[\frac{\int_{t_1}^{t_2} A_R . dt}{(t_2 - t_1)}\right]^{2.5}$$

$$A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Where, *Ax*, *Ay* and *Az* are acceleration values of the head in three directions, in g.

t_2-t_1≤15 ms (for rating), t_2-t_1≤36 ms (for reference).

Neck calculation:

$$N_{ij} = (F_z/F_{zc}) + (M_{OCy}/M_{yc})$$

$$M_{OCy} = M_y - (D \bullet F_x)$$

Where, *Fz* is the axial force on neck, in N;

Fzc is the critical axial force on neck, in N;

Fx is the shear force on neck, in N;

My is the tensile/compressive bending moment of neck, in Nm;

Myc is the critical tensile/compressive bending moment of neck, in Nm;

D (0.01778), in m, is the distance between the center of the neck force sensor and the center of the head-neck connecting shaft.

Table C.6 Critical Values for N_{ij} Calculation

ATD Type	*Fzc* - axial tensile force	*Fzc* - axial compressive force	*Myc* - compressive bending moment	*Myc* - tensile bending moment
Hybrid III 50th	6806N	-6160N	310Nm	-135Nm

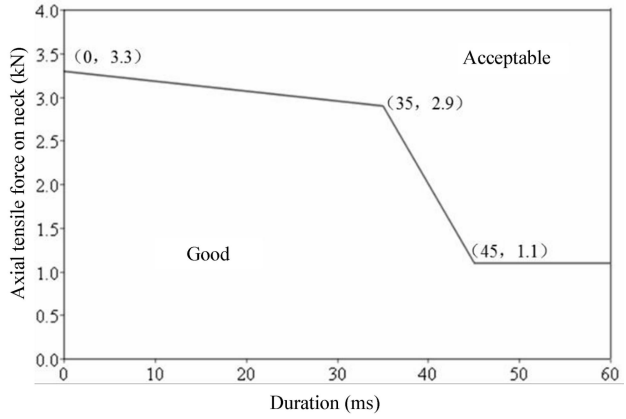


Fig. C.5 Curve of Duration vs. Tensile Force on Neck Fz

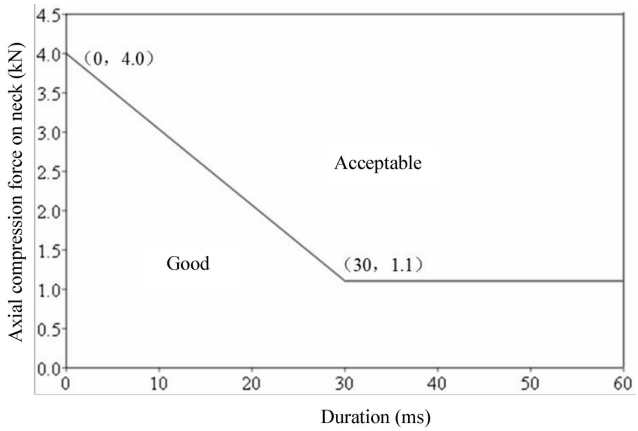


Fig. C.6 Curve of Duration vs. Compressive Force on Neck Fz

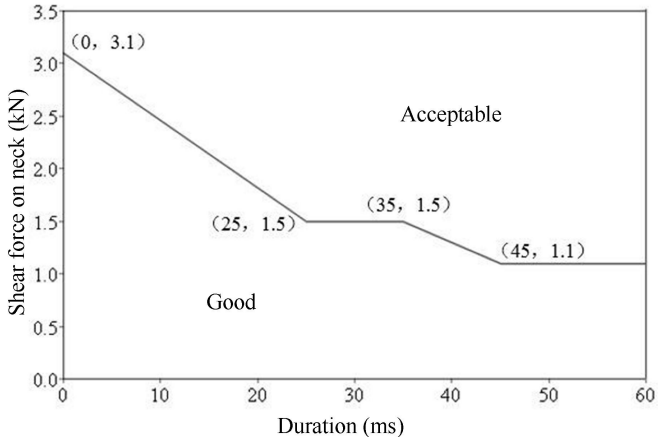


Fig. C.7 Curve of Duration vs. Shear Force on Neck Fx

C.3.2.2 Chest

Chest rating indexes: continuous acceleration A_3 ms, compression deformation D, compression velocity V, and viscous criterion VC.

VC calculation:

$$(VC)_t = 1.3V_t \times C_t$$

$$C_t = \frac{D_t}{0.229}$$

The chest compression velocity at time point t is calculated from the filtered compression deformation (filtering level CFC60).

$$V_t = \frac{8\left[D_{(t+1)} - D_{(t-1)}\right] - \left[D_{(t+2)} - D_{(t-2)}\right]}{12\delta t}$$

Where, Dt is the deformation at time point t, in m; δt is the time interval for compression deformation measurement, in s.

C.3.2.3 Thigh and hip

Thigh and hip rating indexes: knee-thigh-hip (KTH) injury risk, compressive force Fz on thigh (for reference but not for rating).

KTH injury risk is determined according to Fig. C.9 based on the compressive force and impulse value of each thigh. The impulse value is obtained by integrating the force on thigh from the beginning of thigh compression to 4050 N after the peak force is reached, as shown in Fig. C.8.

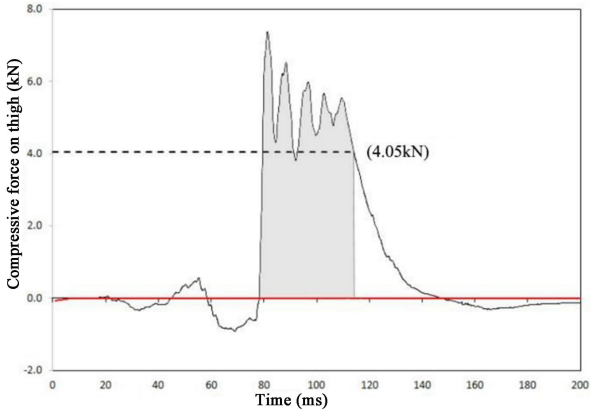


Fig. C.8 Thigh Impulse on Hybrid III 50th ATD

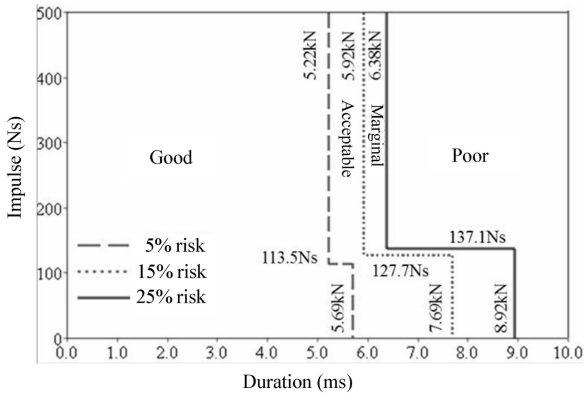


Fig. C.9 KTH Injury Risk

C.3.2.4 Tibia and foot

Tibia rating indexes: axial compressive force on upper tibia and lower tibia Fz, knee joint sliding displacement D, and tibia index TI.

Tibia index TI is calculated with the adjusted bending moment M_y.

$$M_{Y\ upper\ adjustment} = M_{Y\ upper\ measured\ value} - [(F_{Z\ tibia})\ (0.02832)]$$

$$M_{Y\ lower\ adjustment} = M_{Y\ lower\ measured\ value} + [(F_{Z\ tibia})\ (0.006398)]$$

Note: The bending moment is measured in Nm, and the force in N.

TI calculation:

$$M_R = \sqrt{(M_X)^2 + \left(M_{Y\ \text{adjustment}}\right)^2}$$

$$\text{TI} = |M_R/(M_C)_R| + |F_Z/(F_C)_z|$$

Where, M_X is the bending moment around X axis, M_Y adjustment is the adjusted bending moment around Y axis, $(M_C)_R$ is critical bending moment, F_Z is axial compressive force in Z direction, and $(F_C)_Z$ is critical compressive force in Z direction.

Foot rating index: maximum resultant foot acceleration.

Table C.7 ATD Injury Rating

Body Parts	Parameters	Good	Acceptable	Marginal	Poor
Head and neck	HIC_{15}	≤560	≤700	≤840	＞840
	N_{ij}	≤0.80	≤1.00	≤1.20	＞1.20
	Tensile force F_Z (kN)*	≤2.6	≤3.3	≤4.0	＞4.0
	Compressive force F_Z (kN)*	≤3.2	≤4.0	≤4.8	＞4.8
Chest	Acceleration A_3 ms (g)	≤60	≤75	≤90	＞90
	Compression deformation D (mm)	≤50	≤60	≤75	＞75
	Compression velocity V (m/s)	≤6.6	≤8.2	≤9.8	＞9.8
	Viscous criterion VC (m/s)	≤0.8	≤1.0	≤1.2	＞1.2
Thigh and hip	KTH Injury Risk	≤5%	≤15%	≤25%	＞25%
Tibia and foot	Knee joint sliding displacement D (mm)	≤12	≤15	≤18	＞18
	Tibia index (upper and lower), TI	≤0.80	≤1.00	≤1.20	＞1.20
	Axial force on tibia F_Z (kN)	≤4.0	≤6.0	≤8.0	＞8.0
	Maximum resultant foot acceleration, A (g)	≤150	≤200	≤260	＞260

* See Fig. C.5 and Fig. C.6 for curves of duration vs. axial force on neck.

C.3.3 Rear passenger injury rating (monitoring)

Rate the ATD injury with the measured injury values of the Q6 and Q10 child ATDs. See Table C.8 for ATD measurement parameters and filtering level.

Table C.8 Q6/Q10 ATD Measurement Parameters and Filtering Level

Measuring Parts	Measurement Parameters	Filtering Level
Head	Acceleration Ax, Ay, Az	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Upper neck	Force Fx, Fy, Fz	CFC 1000
	Moment My	CFC 600
Chest	Acceleration Ax, Ay, Az	CFC 180
	Compression deformation D	CFC 180

The ATD injury rating involves three parts: head, upper neck, and chest.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part.

C.3.3.1 Head

Head rating indexes: HIC_{15}, cumulative 3 ms resultant acceleration.

Head HIC is also calculated with the Hybrid III 50^{th} ATD.

C.3.3.2 Upper neck

Upper neck rating indexes: axial tensile force Fz and tensile bending moment My.

C.3.3.3 Chest

Chest rating indexes: compression deformation D, and cumulative 3 ms resultant acceleration.

C.4 Vehicle structure and compatibility rating

C.4.1 Vehicle Structure Rating

C.4.1.1 Rating by intrusion measurement

The vehicle structure is rated by intrusion measurement (see Fig. C.10), and the rating is corrected (degraded) according to the qualitative observation result of the structural integrity of the passenger compartment.

The measuring points used for vehicle structure rating are on the driver's side, mainly including left footrest, left toepan, middle toepan, right toepan, brake pedal, lower left instrument panel, lower right instrument panel and intrusion between A-pillar and B-pillar.

Compare the X-Y-Z resultant displacement of the left footrest, left toepan, middle toepan, right toepan, brake pedal, lower left instrument panel, lower right instrument panel, and intrusion between A-pillar and B-pillar with the rating reference value (see Fig. C.10). For each measuring point, if it moves forward along X axis (away from the passenger seat), only the Y-Z resultant displacement is compared with the rating reference value. Only use the displacement in the X direction for the rating of intrusion between A-pillar and B-pillar, lower left instrument panel and lower right instrument panel.

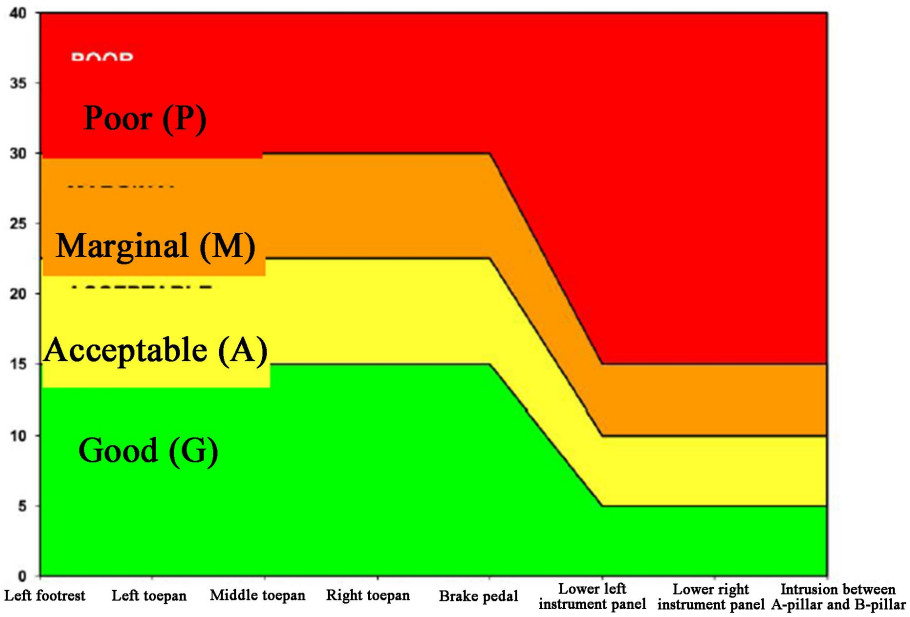


Fig. C.10 Passenger Compartment Intrusion Rating

If the intrusion measurement falls within different rating ranges, the structure rating is

the rating for the area with the most measured values, but it shall not be more than one level higher than the rating for the area with the worst measured value. If half of the measurement results are in the area of the same rating, while the other half in the area of another rating, the structure rating is the lower rating. The higher rating is taken if the intrusion lies on the boundary of two different ratings.

The structure measuring points of the passenger compartment are rated according to the thresholds of rating indexes. See Table C.9 for specific rating requirements:

Table C.9 Vehicle Structure Rating

Rating Object	Evaluation Index	Good	Acceptable	Marginal	Poor
Left footrest	Resultant displacement (cm)	≤15	≤22.5	≤30	>30
Left toepan					
Middle toepan					
Right toepan					
Brake pedal					
Lower left instrument panel	Backward intrusion (cm)	≤5	≤10	≤15	>15
Lower right instrument panel					
Intrusion between A-pillar and B-pillar					
Number of defects corresponding to vehicle structure rating		0	1	2	4

C.4.1.2 Qualitative observation of vehicle structure rating

If the ATD's feet are stuck and can only be taken out with tools, the hinge pillar is completely torn, and the front wall is torn in a large area (for example, the tearing length is greater than 20 cm, and the width is greater than 5 cm), the vehicle structure rating shall be degraded by one level from the rating of intrusion measurement.

C.4.2 Vehicle compatibility rating

The compatibility of the VUT is rated according to three indexes: standard deviation (SD) of aluminum honeycomb barrier deformation at the front end of MPDB sled, occupant load criterion (OLC) of sled, and barrier intrusion depth ("bottoming out" or not). The limits corresponding to each rating index level are shown in Table C.10.

Table C.10 Vehicle Compatibility Rating

Rating Object	Evaluation Index	Good	Acceptable	Marginal	Poor
Aluminum honeycomb barrier	Standard deviation (SD) of deformation (mm)	≤80	≤115	≤150	>150
	Number of continuous cells with an intrusion depth greater than 630 mm (size of each cell: 20 mm x 20 mm)	≤4			>4
Barrier sled	Sled OLC (g)	≤34	≤38	≤42	>42

C.4.2.1 Standard deviation (SD) of aluminum honeycomb barrier deformation

C.4.2.1.1 Barrier rating area

The rating area of aluminum honeycomb barrier deformation is rectangular (as shown in Fig. C.11), with the upper boundary 650 mm above the ground and the lower boundary 250 mm above the ground (100 mm from the lower edge of the barrier). The left boundary is

related to the width of the VUT, and the distance from the right edge of the MPDB surface is 45% of the vehicle width, and the right boundary is 200 mm from the right edge of the MPDB surface.

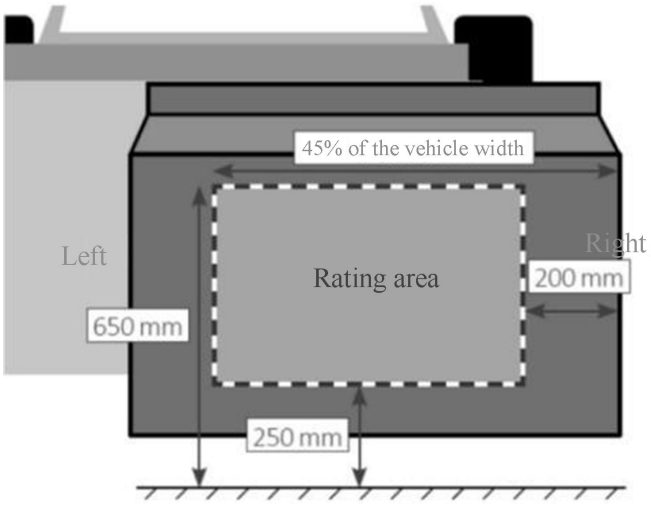


Fig. C.11 Schematic Diagram of Aluminum Honeycomb Barrier Deformation Rating Area

C.4.2.1.2 Barrier scanning data

Use a three-coordinate measuring instrument to scan the deformed aluminum honeycomb barrier after a crash to generate a grid with a maximum cell size of not more than 10 mm. Project the equidistant grid points with a side length of 20 mm created on the barrier surface before the test (1400 points in total) to the surface of the deformed barrier along the crash direction, and calculate the intrusion of each grid point in the rating area.

C.4.2.1.3 Calculation of standard deviation of deformation

The standard deviation (SD) of aluminum honeycomb barrier deformation is used to rate the deviation of the sample cell from the average value in the rating area, that is, the uniformity of aluminum honeycomb deformation. The standard deviation of aluminum honeycomb MPDB deformation is calculated according to the following formula:

$$SD = \sqrt{\frac{\sum_{i=1}^{n} (X_n - \overline{x})^2}{n-1}}$$

Where, *SD* is the standard deviation of aluminum honeycomb barrier deformation, in mm; X_n is the intrusion of the sample point, in mm; $\overline{x}$ is the average intrusion depth, in mm.

C.4.2.2 Occupant load criterion (OLC) of sled

C.4.2.2.1 Definition of OLC

Assuming that there is a virtual ATD wearing a restraint system on the moving MPDB sled. At the beginning of the crash, the corresponding time when the virtual ATD on the MPDB sled first moves forward freely for 65 mm is t_1; after t_1, the virtual ATD starts to move

forward for 235 mm under the action of the restraint system, and the corresponding time is t_2 at this moment. Assuming that the deceleration of the virtual ATD during the forward motion under the action of the restraint system is constant from t_1 to t_2, the constant deceleration is defined as OLC (converted to g in unit), i.e.:

$$\int_{t=0}^{t=t_1} V_0 dt - \int_{t=0}^{t=t_1} V(t) dt = 0.065$$

$$\int_{t=t_1}^{t=t_2} (V_0 - OLC_{SI} * (t - t_1)) \, dt - \int_{t=t_1}^{t=t_2} V(t) dt = 0.235$$

Where, V_0 is the initial velocity of the sled, in m/s; $V(t)$ is the velocity of the sled at time t, in m/s; OLC_{SI} is the slope of the velocity curve of the virtual ATD from time t_1 to time t_2 during the crash, in m/s^2.

C.4.2.2.2 Calculation of OLC

The velocity curve V_t (CFC180 filter) of MPDB is obtained by integrating the X-direction acceleration curve A_X at the center of mass of MPDB, i.e.:

$$V(t) = \int A_X(t) \, dt + V_0$$

Then, OLC is calculated according to the following formula.

$$V(t) = V_0 - OLC_{SI} * (t - t_1)$$

$$V(t_2) = V_0 - OLC_{SI} * (t_2 - t_1)$$

$$OLC = OLC_{SI} / 9.81$$

Where, V_0 is the initial velocity of the sled, in m/s; $V(t)$ is the velocity of the sled at time t, in m/s;

t_1 is the moment when the virtual ATD moves 65 mm relative to the sled during the crash, in s;

t_2 is the moment when the virtual ATD moves another 235 mm relative to the sled during the crash, in s;

OLC_{SI} is the slope of the velocity curve of the virtual ATD from t_1 to t_2 during the crash, in m/s^2;

OLC is the occupant load criterion index of the sled, in g.

C.4.2.3 Barrier intrusion depth

In the aluminum honeycomb barrier deformation rating area shown in Fig. C.11, if the aluminum honeycomb barrier area with a penetration depth of 630 mm is greater than 40 mm

× 40 mm (i.e., the number of continuous cells is greater than 4), it is defined as "bottoming out". When "bottoming out" occurs, the rating of this index is poor, and 2 defects are counted.

C.4.3 Vehicle structure and compatibility rating

The vehicle structure and compatibility shall be rated according to the number of defects specified in Table C.11.

Table C.11 Vehicle Structure and Compatibility Rating

Rating Object	Evaluation Index	Good	Acceptable	Marginal	Poor
Vehicle structure	Measuring point intrusion	0	1	2	4
Aluminum honeycomb barrier	Standard deviation (SD) of deformation	0	1	2	4
	Bottoming out or not	0			2
Barrier sled	Sled OLC	0	1	2	4*
Vehicle structure and compatibility rating (number of defects)		≤1	≤3	≤5	>5

*__Note__: For a VUT with OLC greater than 42, if the SD rating is "Good" (SD≤80), one defect can be exempted from the vehicle structure and compatibility rating, but the structural defects of the VUT are not within the exemption scope.

C.4.4 Integrity of fuel system and high voltage system

In case of obvious fuel leakage or damage to the high voltage system (for example, battery pack damage) during the test, the vehicle structure and compatibility rating and overall rating will be degraded to "Poor".

Obvious fuel leakage means that more than 28 g of fuel leaks from crash to vehicle standstill, and more than 142 g leaks in the following 5 min, and 28 g leaks per minute in the next 25 min.

The high voltage system must meet the requirements for electrolyte leakage, REESS safety, and electric shock protection in GB/T 31498-2021 *Post Crash Safety Requirement for Electric Vehicle*, so as to avoid level degrading. The specific requirements are summarized as follows:

- Requirements for electrolyte leakage

  Within 30 min after the crash, there shall be no electrolyte overflowing from the REESS to the passenger compartment and no over 5.0 L of electrolyte overflowing from the REESS.

- Requirements for REESS safety

① The REESS located in the passenger compartment shall remain in the installation position, REESS components shall be kept within the housing, and any part of the REESS located outside the passenger compartment shall not enter the passenger compartment.

② Within 30 min after the end of crash, the REESS shall not explode or catch fire.

- Requirements for electric shock protection

Electric shock protection involves four rating indexes: voltage, electric energy, physical protection and insulation resistance requirements. Each high voltage bus shall meet at least one of the four rating indexes. If the crash test is carried out with the REESS of the vehicle actively disconnected from the balance of electric power system, the balance of electric power system of the vehicle shall meet the requirements for physical protection or insulation resistance; the REESS and high voltage bus for charging shall meet one of the four rating indexes:

① Voltage requirements

The voltages V_b, V_1 and V_2 of high voltage bus measured according to GB/T 31498-2021 *Post Crash Safety Requirement for Electric Vehicle* shall not exceed 30 V AC or 60 V DC.

② Electric energy requirements

Both the total electric energy TE on the high voltage bus and the energy (TEy1, TEy2) stored in Y-capacitor shall be less than 0.2 J.

③ Physical protection

To prevent direct contact with high-voltage live parts, the vehicle shall have IPXXB protection after the crash; to prevent electric shock injury caused by indirect contact, the resistance between all exposed conductive parts and electric chassis shall be less than 0.1 Ω as measured with a current higher than 0.2 A. This requirement is deemed to be met when the electrical connection is made by welding.

④ Insulation resistance

If the AC high voltage bus and the DC high voltage bus are subject to conductive insulation with each other, the insulation resistance between the DC high voltage bus and the electric chassis shall be greater than or equal to 100 Ω/V, and the insulation resistance between the AC high voltage bus and the electric chassis shall be greater than or equal to 500 Ω/V.

If the AC high voltage bus and the DC high voltage bus are conductively connected with each other, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 500 Ω/V. After the crash, if the IP rating of all AC high voltage buses reaches IPXXB or the AC voltage is equal to or less than 30 V, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 100 Ω/V.

C.5 Overall rating

The overall rating is based on the vehicle structure and compatibility, the measured injuries of the driver's and front passenger's heads and necks, chests, thighs and hips, and tibias and feet, and the restraint system and ATD motion, and calculated according to Table C.12. The rating of the rear passenger is not included in the overall rating of passengers in the vehicle but only serves as a monitoring item.

Table C.12 Overall Rating

Rating Item	Level			
	Good (G)	Acceptable (A)	Marginal (M)	Poor (P)
Vehicle structure and compatibility	0	2	6	10
Driver				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Tibia and foot	0	1	2	4
Restraint system and ATD motion	0	2	6	10
Front passenger				
Head and neck	0	2	10	20
Chest	0	2	10	20
Thigh and hip	0	2	6	10
Tibia and foot	0	1	2	4
Restraint system and ATD motion	0	2	6	10
Overall rating limit	0-4	5-9	10-19	20+

Note: If two doors in the same row cannot be opened from outside normally without tools after the test, the overall rating will be degraded by one level.

Annex D

Rating Method for Side Impact Crash

D.1 Introduction

The side impact crash rating involves three aspects: restraint system and ATD motion, ATD injury and vehicle structure. This protocol elaborates on the rating methods.

D.2 Restraint system and ATD motion rating

D.2.1 Rating of ATD's head motion protection

ATD's head motion protection is rated by the head motion of the driver and rear passengers. Any contact during rebounding is excluded from the rating.

D.2.1.1 "Good"

D.2.1.1.1 The head is effectively protected by the head protection system (typically an airbag), hard contact of head can be prevented, and the resultant head acceleration is less than or equal to 70 g. The hard contact includes contact with AC-MDB and interior trim surface.

D.2.1.1.2 The head protection rating is not degraded if there is any coincidental contact between the head and the vehicle's loose interior trims beyond the protection of the head protection system, as long as the resultant head acceleration is less than or equal to 70 g.

D.2.1.1.3 Head motion protection cannot be rated as "Good" if the side curtain airbag is stuck and does not fully deploy.

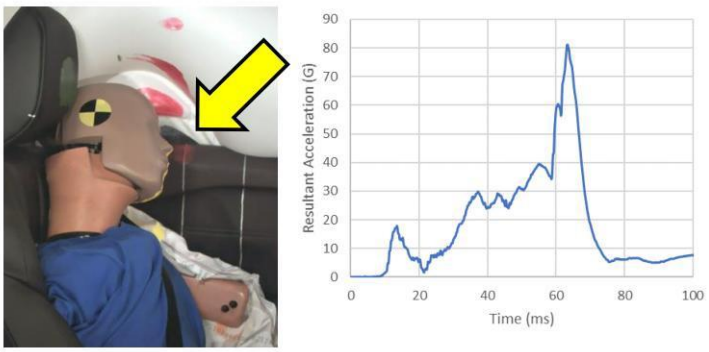
D.2.1.2 "Acceptable"

The head is not adequately protected by a head protection system and comes into contact with the vehicle interior trim (e.g. door window frame, C-pillar), but the resultant head acceleration is less than or equal to 70 g.

D.2.1.3 "Marginal"

D.2.1.3.1 Head protection is rated as "Marginal" if the ATD's head is in direct or indirect contact with the vehicle interior trim surface (for example, bottoming out on the side head protection airbag), and the resultant head acceleration is greater than 70 g.

D.2.1.3.2 If the vehicle is not equipped with a head protection system, the head protection rating shall not be higher than "Marginal".



Note: The ATD's head hits the door interior trim during impact crash, and the resultant head acceleration reaches 80 g.

Fig. D.1 Schematic Diagram for "Marginal"

D.2.1.4 "Poor"

D.2.1.4.1 Head protection is rated as "Poor" if the ATD's head cannot be effectively protected by the head protection system (e.g., the head protection airbag deploys late, fails to deploy, deploys unexpectedly, or is not equipped) or it cannot be kept inside the vehicle and is at risk of contacting any object outside the vehicle.

D.2.1.4.2 Head protection is rated as "Poor" if the ATD's head is in direct contact with the AC-MDB.

D.2.2 Passenger protection and others

In case of failure to unlock the seat belt or excessive unlocking force, the restraint system and ATD motion rating will be degraded by one level. Failure to unlock the seat belt or excessive unlocking force means that the seat belt cannot be unlocked or the unlocking force of the seat belt buckle is greater than 100 N to release the ATD from the restraint system after the crash.

D.3 SID-IIs ATD injury rating

Rate the ATD injury with the measured injury values of the SID-IIs (Version D) ATD, and see Table D.1 for measurement parameters and filtering level of the ATD.

Table D.1 Measurement Parameters and Filtering Level of SID-IIs ATD

Measuring Parts	Measuring Channel	Filtering Level
Head	Acceleration Ax, Ay, Az	CFC 1000
Neck	Force Fx, Fy, Fz	CFC 1000
	Moment Mx, My, Mz	CFC 600
Shoulder	Force Fx, Fy, Fz	CFC 600
	Compression deformation Dy	CFC 600
Vertebra	T1 acceleration Ay	CFC 180
	T4 acceleration Ay	CFC 1000
	T12 acceleration Ay	CFC 1000
Chest and abdomen	Compression deformation D_y of (upper, middle and lower) ribs at chest	CFC 600
	Acceleration A_y of (upper, middle and lower) ribs at chest	CFC 1000

Measuring Parts	Measuring Channel	Filtering Level
	Compression deformation D_y of (upper and lower) ribs at abdomen	CFC 600
	Acceleration A_y of (upper and lower) ribs at abdomen	CFC 1000
Pelvis	Force on hip bone Fy	CFC 600
	Force on iliac bone Fy	CFC 600
	Pelvis acceleration Ay	CFC 1000

The ATD injury rating involves three parts: head and neck, torso and pelvis.

The injury of each part is rated as Good, Acceptable, Marginal or Poor according to the corresponding indexes. The worst result of each body part rating index is taken as the overall rating of this part.

D.3.1 Head and neck

The rating of head and neck is determined by three indexes: head HIC_{15}, and axial tensile force Fz and axial compressive force Fz on the neck (see Table D.2).

Table D.2 Rating of ATD's Head and Neck

Evaluation Index	Good	Acceptable	Marginal	Poor
HIC_{15}	≤623	≤779	≤935	>935
Axial tensile force on neck F_z (kN)	≤2.1	≤2.5	≤2.9	>2.9
Axial compressive force on neck F_z (kN)	≤2.5	≤3.0	≤3.5	>3.5

Head calculation:

$$HIC = (t_2 - t_1)\left[\frac{\int_{t_1}^{t_2} A_R . dt}{(t_2 - t_1)}\right]^{2.5}$$

$$A_R = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

Where, *Ax*, *Ay* and *Az* represent the acceleration of the head in three directions, in g;

t_2-t_1≤15 ms.

D.3.2 Torso

The torso rating is determined by three indexes: compression deformation, deformation velocity and viscous criterion VC of the chest and abdomen (see Table D.3).

Table D.3 Torso Rating

Evaluation Index	Good	Acceptable	Marginal	Poor
Average compression deformation (mm)	≤28	≤38	≤48	>48
Peak compression deformation (mm)	——	——	51~55	>55
Viscous criterion VC (m/s)	≤1.0	≤1.2	≤1.4	>1.4
Deformation velocity (m/s)	≤8.2	≤9.8	≤11.5	>11.5

Evaluation Index	Good	Acceptable	Marginal	Poor
Shoulder displacement (mm)	If the shoulder "bottoms out" or its deformation exceeds 60 mm, the torso rating will be degraded by one level. Shoulder rib bottoming out can be identified by the peak force on shoulder and shoulder deformation curve, as shown in Fig. D.2.			

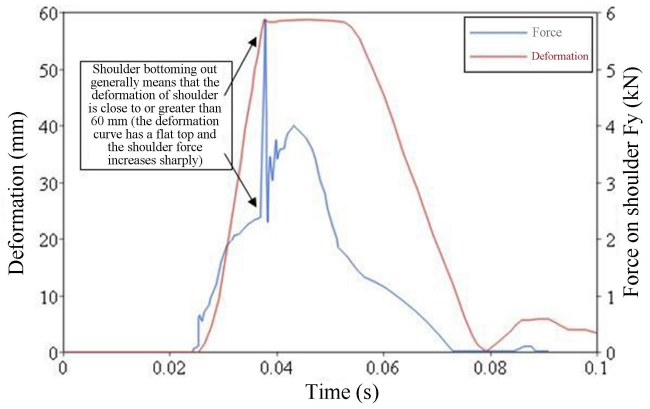


Fig. D.2 Example of Shoulder Bottoming Out

D.3.2.1 Deformation

If the peak compression deformation of each of the 5 ribs at the chest and abdomen is ≤ 50 mm, this rating will be determined based on the average of the peak compression deformation of 5 ribs. If the peak compression deformation of any rib at the chest and the abdomen is > 50 mm, this rating will be determined based on this peak compression deformation.

D.3.2.2 Deformation velocity

The rib deformation velocity is obtained by differentiating the rib deformation data, and the calculation formula is as follows:

$$V(t)_i = \dot{D(t)}_i$$

Where, $D(t)i$ = deformation of rib i at time point t (filtering level CFC180), in mm.

D.3.2.3 Viscous criterion

The rib viscous criterion (VC) is obtained by calculating the chest half width and rib deformation velocity, and the calculation formula is as follows:

$$VC(t)_i = 1.0 * V(t)_i * \frac{D(t)_i}{138mm}$$

Where, $V(t)i$ = deformation velocity of rib, in m/s;

$D(t)i$ = deformation of rib i at time point t, in mm.

D.3.3 Pelvis

The pelvis rating is determined by the peak resultant force on hip bone and iliac bone $F_P(t)$ (see Table D.4).

Table D.4 Rating of Pelvis and Leg

Evaluation Index	Good	Acceptable	Marginal	Poor
Resultant force on iliac bone and hip bone $F_P(t)$ (kN)	≤4.0	≤5.0	≤6.0	>6.0

The resultant force on hip bone and iliac bone $F_P(t)$ is calculated according to the following formula:

$$F_P(t)=F_A(t)+F_I(t)$$

Where, $F_A(t)$ = force on hip bone at time point t;

$F_I(t)$ = force on iliac bone at time point t.

D.4 World SID 50th ATD injury rating (monitoring item)

Rate the ATD injury with the measured injury values of the World SID 50th ATD, and see Table D.5 for measurement parameters and filtering level of the ATD.

Table D.5 Measurement Parameters and Filtering Level of World SID 50th ATD

Measuring Parts	Measuring Channel	Filtering Level
Head	Acceleration Ax, Ay, Az	CFC 1000
	Angular velocity ω_x, ω_y, ω_z	CFC 60
Upper neck	Force Fx, Fy, Fz	CFC 1000
	Moment Mx, My, Mz	CFC 600
Lower neck	Force Fx, Fy, Fz	CFC 1000
	Moment Mx, My, Mz	CFC 600
Shoulder	Force Fx, Fy, Fz	CFC 600
	Compression deformation D	CFC 180
Chest	Displacement D of (upper, middle and lower) ribs	CFC 180
	Rotation angle α of (upper, middle and lower) ribs	CFC 180
Abdomen	Compression deformation D of (upper and lower) ribs	CFC 180
	Rotation angle α of (upper and lower) ribs	CFC 180
Pelvis	Force on hip bone Fy	CFC 600
	Force on iliac bone Fy	CFC 600
	Pelvis acceleration Ax, Ay, Az	CFC 600
T12	Acceleration Ax, Ay, Az	CFC 180
Lumbar spine	Force Fx, Fy, Fz	CFC 600
	Moment Mx, My, Mz	CFC 600

See Table D.6 for specific monitoring indexes of World SID 50th ATD.

Table D.6 Monitoring Indexes of World SID 50th ATD Body Parts

Part	Monitoring Indexes
Head	HIC_{15}
	3 ms resultant acceleration (g)
	BrIC
Upper and lower necks	Tensile force on neck Fz
	Mx
	Tensile bending moment My
Chest and abdomen	Chest compression (upper, middle and lower)
	Viscous criterion (VC) of chest
	Abdomen compression (upper and lower)
	Viscous criterion (VC) of abdomen
Pelvis and lumbar spine	Force on pubis
	Force on iliac bone
	Lumbar spine Fy, Fz
	Lumbar spine Mx

D.5 Vehicle structure rating

D.5.1 Rating by intrusion measurement

The vehicle structure rating is mainly based on the distance between the B-pillar and the driver seat centerline after the test (see Table D.7 and Fig. D.3), and will be corrected according to whether the vehicle structure members fail.

The effective rating area of the distance between the B-pillar and the driver seat centerline ranges from 540 mm above the H-point of the inner side surface of B-pillar to 100 mm below the H-point, where the H-point is measured when the seat is at the rearmost and lowest position.

Table D.7 Vehicle Structure Rating

Evaluation Index	Good	Acceptable	Marginal	Poor
Distance between B-pillar and driver seat centerline (cm)	≥18.0	≥14.0	≥10.0	＜10.0
Structural part failure (e.g., B-pillar is completely broken)	The vehicle structure rating is degraded by one level.			

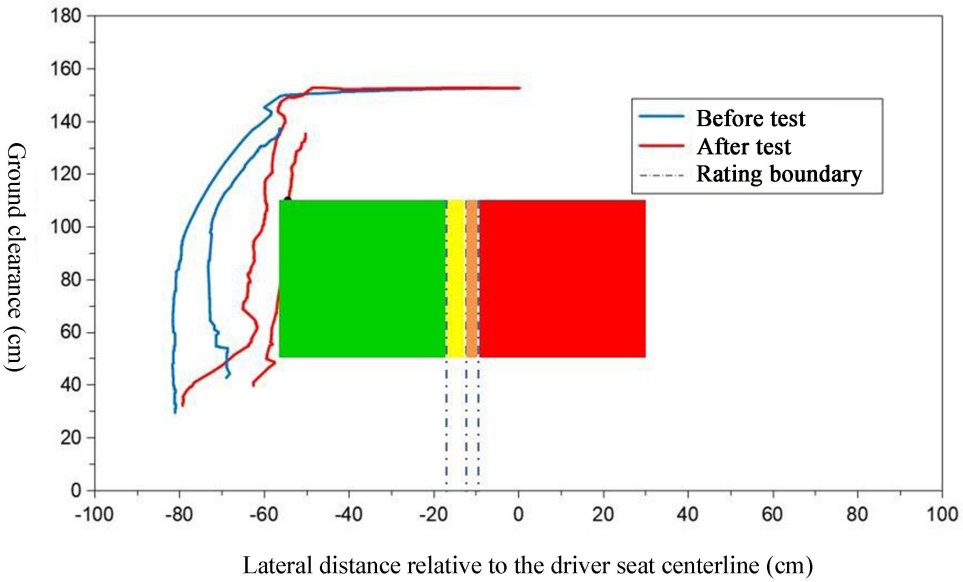


Fig. D.3A Vehicle Structure Rating

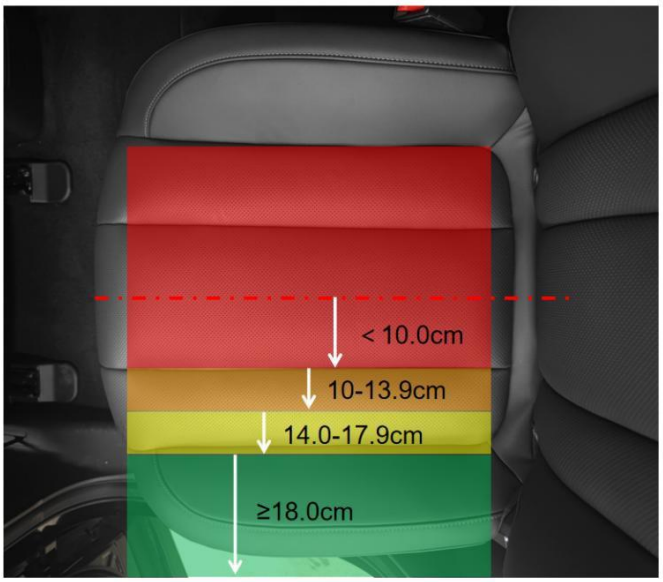


Fig. D.3B Vehicle Structure Rating (Seat for Example)

D.5.2 Integrity of fuel system and high voltage system

In case of obvious fuel leakage or damage to the high voltage system (for example, battery pack damage) during the test, the vehicle structure rating and overall rating will be degraded to "Poor".

Obvious fuel leakage means that more than 28 g of fuel leaks from crash to vehicle standstill, and more than 142 g leaks in the following 5 min, and 28 g leaks per minute in the next 25 min.

The high voltage system must meet the requirements for electrolyte leakage, REESS safety, and electric shock protection in GB/T 31498-2021 *Post Crash Safety Requirement for Electric Vehicle*, so as to avoid level degrading. The specific requirements are summarized as

follows:

- Requirements for electrolyte leakage

Within 30 min after the crash, there shall be no electrolyte overflowing from the REESS to the passenger compartment and no over 5.0 L of electrolyte overflowing from the REESS.

- Requirements for REESS safety

① The REESS located in the passenger compartment shall remain in the installation position, REESS components shall be kept within the housing, and any part of the REESS located outside the passenger compartment shall not enter the passenger compartment.

② Within 30 min after the end of crash, the REESS shall not explode or catch fire.

- Requirements for electric shock protection

Electric shock protection involves four rating indexes: voltage, electric energy, physical protection and insulation resistance requirements. Each high voltage bus shall meet at least one of the four rating indexes. If the crash test is carried out with the REESS of the vehicle actively disconnected from the balance of electric power system, the balance of electric power system of the vehicle shall meet the requirements for physical protection or insulation resistance; the REESS and high voltage bus for charging shall meet one of the four rating indexes:

① Voltage requirements

The voltages V_b, V_1 and V_2 of high voltage bus measured according to GB 31498-2021 *Post Crash Safety Requirement for Electric Vehicle* shall not exceed 30 V AC or 60 V DC.

② Electric energy requirements

Both the total electric energy TE on the high voltage bus and the energy (TEy1, TEy2) stored in Y-capacitor shall be less than 0.2 J.

③ Physical protection

To prevent direct contact with high-voltage live parts, the vehicle shall have IPXXB protection after the crash; to prevent electric shock injury caused by indirect contact, the resistance between all exposed conductive parts and electric chassis shall be less than 0.1 Ω as measured with a current higher than 0.2 A. This requirement is deemed to be met when the electrical connection is made by welding.

④ Insulation resistance

If the AC high voltage bus and the DC high voltage bus are subject to conductive insulation with each other, the insulation resistance between the DC high voltage bus and the electric chassis shall be greater than or equal to 100 Ω/V, and the insulation resistance between the AC high voltage bus and the electric chassis shall be greater than or equal to 500 Ω/V.

If the AC high voltage bus and the DC high voltage bus are conductively connected with each other, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 500 Ω/V. After the crash, if the IP rating of all AC high voltage buses reaches IPXXB or the AC voltage is equal to or less than 30 V, the insulation resistance between the high voltage bus and the electrical chassis shall be greater than or equal to 100 Ω/V.

D.6 Overall rating

The overall rating is determined according to Table D.8 based on the vehicle structure, restraint system and ATD motion, and ATD's head and neck, torso, and pelvis.

Table D.8 Overall Rating

Rating Item	Good (G)	Acceptable (A)	Marginal (M)	Poor (P)
Vehicle structure	0	2	10	22
Driver				
Restraint system and ATD motion	0	2	10	22
Head and neck	0	2	10	35
Torso	0	2	10	35
Pelvis	0	2	6	10
Rear passengers				
Restraint system and ATD motion	0	2	10	22
Head and neck	0	2	10	35
Torso	0	2	10	35
Pelvis	0	2	6	10
Overall rating limit	0~8	9~20	21~34	35+

Note: If the door opens during the test or if both doors in the same row cannot be opened normally without the aid of tools after the test, the overall rating will be degraded by one level.