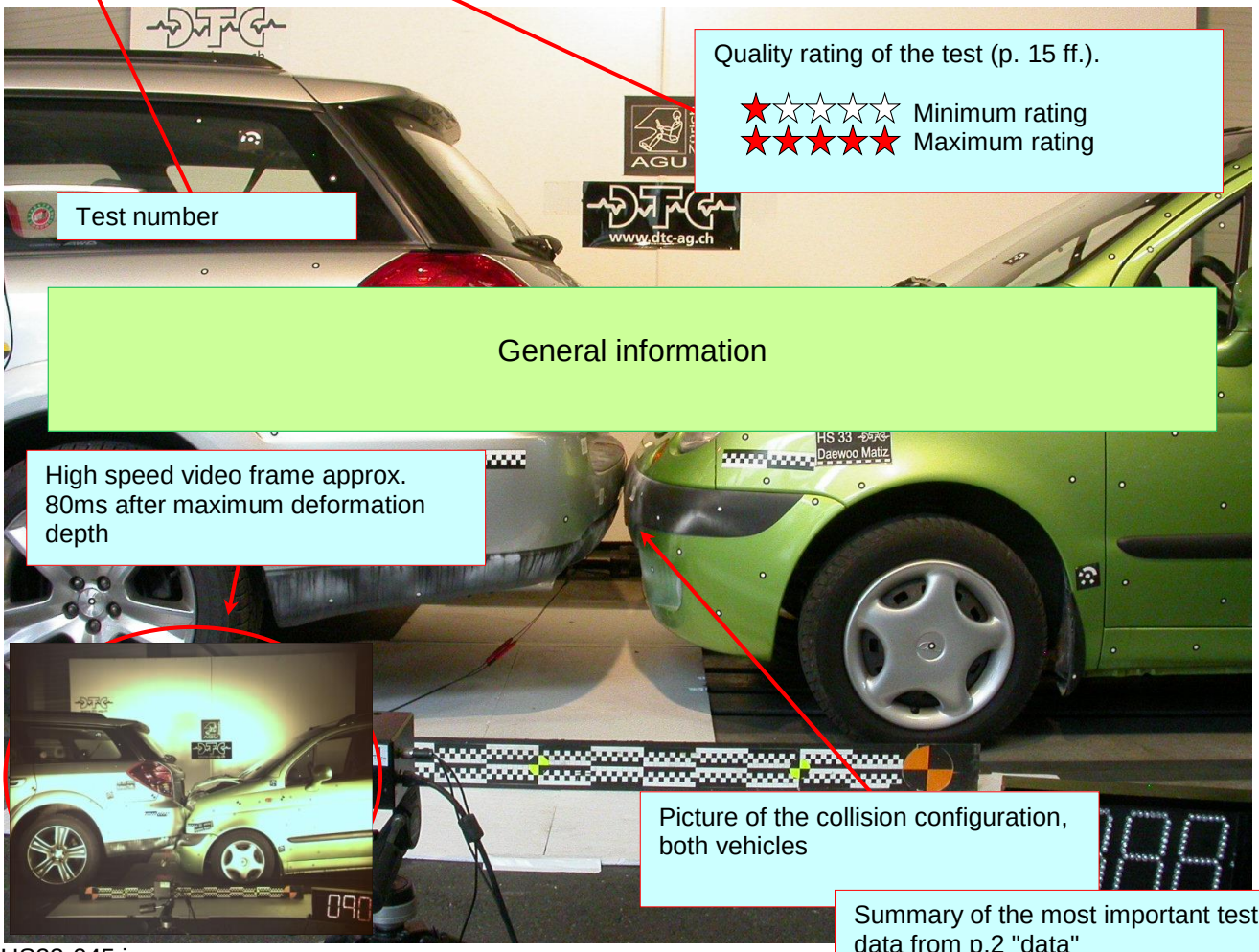
VALID FOR ALL TESTS WITH NUMBERS HS-XX

## Rear-end collision 100% 0° braked — Overview




HS33-045.jpg

Braked (0.4 sec. pre-collision; 7.3 m/s$^2$) collision of a Daewoo Matiz against a Subaru Outback (not braked, gear not engaged).

| Crash Test Results | Bullet vehicle | Target vehicle |
|---|---|---|
| Vehicle | Daewoo Matiz | Subaru Outback |
| Mass | 951.5 kg | 1704.5 kg |
| Brake action | 0.4 s pre collision; 7.3 m/s$^2$ | - |
| Collision velocity $v_K$ | 26.0 km/h * | 0 km/h |
| Change of velocity delta-v $\Delta v_{Res}$ | 20.8 km/h ** | 9.9 km/h ** |
| Max. acceleration $a_{Res\ max}$ | 14.6 g * | 11.3 g * |
| Average acceleration $a_{Res\ dt}$ | 5.6 g * | 2.6 g * |
| Collision duration dt | 104 ms * | |
| Collision factor k / separation velocity $\Delta v'$ | 0.17 ** / 4.5 km/h ** | |
| Total deformation energy $W_{Def\ Ges}$ | 16.6 kJ ± 10% | |
| Energy Equivalent Speed EES | 20.8 ± 1 km/h | 3.2 ± 1.5 km/h |
| Stiffness | 700 kN/m ± 20% | 1000 kN/m ± 20% |
| Total calculated repair cost | 8624.55 CHF | 1961.60 CHF |

* : measured according to SAE J211 (± 3%)
** : calculated according to SAE J211 (± 3%)
*** : optical speed measurement (± 1%)

Version / Revisions of the documentation

VALID FOR ALL TESTS WITH NUMBERS HS-XX

## Rear-end collision 100% 0° braked — Data

Collision velocity vK
velocity change Δv

| Vehicles | Bullet vehicle | | Target Vehicle | |
|---|---|---|---|---|
| Make and Model | Daewoo Matiz | | Subaru Outback | |
| Type | 0.8i 5 Door | | 3.0 AWD 5 Door | |
| Frame number | KLA 4M 11C D2C 808 920 | | JF1 BPE LUA 5G 022 957 | |
| Year (first registration) | 07/2002 | | 10/2004 | |
| Mileage | 29100 km | | 17350 km | |
| Test weight | 952 kg | | 1704.5 kg | |
| Wheel weights FL FR | 286.5 kg | 280.5 kg | 494 kg | 448.5 kg |
| Wheel weights RL RR | 198 kg | 187 | | |
| Tyres | 155/65 R13 | 2.1 | | |
| Brake action | 0.4 s pre collsion; 7.3 m/s | | - | |
| Remarks | - | | - | |

$\Delta v_x = ***$ measured from displaceme nt
** calculated by integratin g

$$\Delta v_x = \int_{t_0}^{t_E} a_x dt$$

| Velocities | | |
|---|---|---|
| $v_K$ | 26.0 km/h * | 0 km/h |
| $\Delta v_x$ | -20.7 km/h ** | 9.8 km/h *** |
| $\Delta v_y$ | 1.0 km/h ** | -0.2 km/h ** |
| $\Delta v_z$ | 0.3 km/h ** | -1.4 km/h ** |
| $\Delta v_{Res}$ | 20.8 km/h ** | 9.9 km/h ** |

$$\Delta v_y = \int_{t_0}^{t_E} a_y dt$$

| Acc | | | | | | |
|---|---|---|---|---|---|---|
| $a_{x\,max}$ | -14.3 g * | 3.5 g * | 5.2 g * | 8.6 g * | -3.6 g * | -7.6 g * |
| $a_{Res\,max}$ | 14.6 g * | | | 11.3 g * | | |
| $a_{x\,dt}$ / $a_{y\,dt}$ / $a_{z\,dt}$ | -5.6 g * | 0.3 g * | 0.1 g * | 2.6 g * | -0.1 g * | -0.4 g * |
| $a_{Res\,dt}$ | 5.6 g * | | | 2.6 g * | | |

$$\Delta v_z = \int_{t_0}^{t_E} a_z dt$$

| | |
|---|---|
| Impact time dt | 104 ms * |
| Impact factor k / ' digkeit Δv' | 0.17 ** / 4.5 km/h ** |

$$\Delta v_{Res} = \sqrt{\Delta v_x^{\,2} + \Delta v_y^{\,2} + \Delta v_z^{\,2}}$$

| | | |
|---|---|---|
| Total deformation energy $W_{Def\,Ges}$ | [illegible] | |
| Energy Equivalent Speed EES | 20.8 ± 1 km/h | 3.2 ± 1.5 km/h |
| Stiffness | 700 kN/m ± 20% | 1000 kN/m ± 20% |

| Repair calculation | | |
|---|---|---|
| Labour | 2200.00 CHF | 250.00 CHF |
| Additional cost | 390.00 CHF | 10.00 CHF |
| Painting | 1848.90 CHF | 881.45 CHF |
| Spare parts | 3576.50 CHF | 681.60 CHF |
| VAT 7.60 % | 609.15 CHF | 138.55 CHF |
| Grand Total | 8624.55 CHF | 1961.60 CHF |

* : measured according to SAE J211 (± 3%)
** : calculated according to SAE J211 (± 3%)
*** : optical speed measurement (± 1%)

VALID FOR ALL TESTS WITH NUMBERS HS-XX

## Rear-end collision 100% 0° braked — Daten

Maximum acceleration
Mean acceleration
Acceleration components

| | | | | |
|---|---|---|---|---|
| Ge | | | | |
| Da | | | | |

| Vehicles | Bullet vehicle | | Target Vehicle | |
|---|---|---|---|---|
| Make and Model | Daewoo Matiz | | Subaru Outback | |
| Type | 0.8i 5 Türen | | 3.0 AWD 5 Türen | |
| Frame number | KLA 4M 11C D2C 808 920 | | JF1 BPE LUA 5G 022 957 | |
| Year (first registration) | 07/2002 | | 10/2004 | |
| Mileage | 29100 km | | 17350 km | |
| Test weight | 952 kg | | 1704.5 kg | |
| Wheel weights FL FR | 286.5 kg | 280.5 kg | 494 kg | 448.5 kg |
| Wheel weights RL RR | 198 kg | 187 kg | 387.5 kg | 374.5 kg |
| Tyres | 155/65 R13 | 2.1 bar | 215/55 R17 | 2.2 bar |
| Brake action | 0.4 s vor Kollision: 7.3 m/s² | | - | |
| Remarks | | | | |

$$\Delta v_x = \int_{t_0}^{t_E} a_x dt$$

$$a_{y\,max} = \max a_{yi}$$

$$a_{z\,max} = \max a_{zi}$$

| Velocities | | |
|---|---|---|
| $v_K$ | 26.0 km/h * | 0 km/h |
| $\Delta v_x$ | -20.7 km/h ** | 9.8 km/h *** |
| $\Delta v_y$ | 1.0 km/h ** | -0.2 km/h ** |
| $\Delta v$ | 0.3 km/h ** | -1.4 km/h ** |
| $\Delta v$ | 20.8 km/h ** | 9.9 km/h ** |

$$a_{Res\,max} = \max \sqrt{a_{xi}^2 + a_{yi}^2 + a_{zi}^2}$$

| Accelerations | | | | | | |
|---|---|---|---|---|---|---|
| $a_{x\,max}$ / $a_{y\,max}$ / $a_{z\,max}$ | -14.3 g * | 3.5 g * | 5.2 g * | 8.6 g * | -3.6 g * | -7.6 g * |
| $a_{Res\,max}$ | 14.6 g * | | | 11.3 g * | | |
| $a_{x\,dt}$ / $a_{y\,dt}$ / $a_{z\,dt}$ | -5.6 g * | 0.3 g * | 0.1 g * | 2.6 g * | -0.1 g * | -0.4 g * |
| $a_{Res\,dt}$ | 5.6 g * | | | 2.6 g * | | |

| | | |
|---|---|---|
| Impact time dt | 104 ms * | |
| Impact factor k / separation velocity Δv' | 0.17 ** / 4.5 km/h ** | |

$$a_{Res\,dt} = \sqrt{a_{xdt}^2 + a_{ydt}^2 + a_{zdt}^2}$$

| | | |
|---|---|---|
| To | 16.6 kJ ± 10% | |
| Energy Equivalent Speed EES | 20.8 ± 1 km/h | 3.2 ± 1.5 km/h |
| Stiffness | 700 kN/m ± 20% | 1000 kN/m ± 20% |

$$a_{x\,dt} = \frac{\int_{t_0}^{t_E} a_x dt}{t_E - t_0} \qquad a_{y\,dt} = \frac{\int_{t_0}^{t_E} a_y dt}{t_E - t_0} \qquad a_{z\,dt} = \frac{\int_{t_0}^{t_E} a_z dt}{t_E - t_0}$$

| Repair calculation | | |
|---|---|---|
| Labour | 2200.00 CHF | 2 |
| Additional cost | 390.00 CHF | |
| Painting | 1848.90 CHF | 8 |
| Spare parts | 3576.50 CHF | 6 |
| VAT 7.60 % | 609.15 CHF | 1 |
| Grand Total | 8624.55 CHF | 1961.60 CHF |

* : measured according toSAE J211 (± 3%)
** : calculated according toSAE J211 (± 3%)
*** : optical speed measurement(± 1%)

VALID FOR ALL TESTS WITH NUMBERS HS-XX

## Rear-end collision 100% 0° braked — Data

impact time duration dt
coefficient of restitution k
separation velocity Δv'

| | | |
|---|---|---|
| Ge | | |
| Da | | |

| | | | |
|---|---|---|---|
| Ve | Bullet vehicle | Target Vehicle | |
| Ma | Daewoo Matiz | Subaru Outback | |
| Ty | 0.8i 5 Türen | 3.0 AWD 5 Türen | |
| Fra | A 4M 11C D2C 808 920 | JF1 BPE LUA 5G 022 957 | |
| Ye | 07/2002 | 10/2004 | |
| Mil | | 17350 km | |
| Te | | 1704.5 kg | |
| Wh | 6.5 kg | 494 kg | 448.5 kg |
| Wh | 98 kg | 387.5 kg | 374.5 kg |
| Ty | 65 R13 / 2.1 bar | | |
| Bra | s vor Kollision; 7.3 m/s² | | |
| Re | | | |

| | | |
|---|---|---|
| $v_K$ | 26.0 km/h * | |
| $\Delta v_x$ | -20.7 km/h ** | 9.8 km/h *** |
| $\Delta v_y$ | 1.0 km/h ** | -0.2 km/h ** |
| $\Delta v_z$ | 0.3 km/h ** | -1.4 km/h ** |
| $\Delta v_R$ | 20.8 km/h ** | 9.9 km/h ** |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ac | | | | | | |
| $a_{x\,max}$ / $a_{y\,max}$ / $a_{z\,max}$ | 14.5 g * | 3.5 g * | | 8.6 g * | -3.6 g * | -7.6 g * |
| $a_{Res\,max}$ | 14.6 g | | | 11.3 g * | | |
| $a_{x\,dt}$ / $a_{y\,dt}$ / $a_{z\,dt}$ | -5.6 g * | 0.3 g * | 0.1 g * | 2.6 g * | -0.1 g * | -0.4 g * |
| $a_{Res\,dt}$ | 5.6 g * | | | 2.6 g * | | |

| | |
|---|---|
| Impact time dt | 104 ms * |
| Impact factor k / separation velocity Δv' | 0.17 ** / 4.5 km/h ** |

| | | |
|---|---|---|
| Total deformation energy $W_{Def\,Ges}$ | 16.6 kJ ± 10% | |
| Energy Equivalent Speed EES | 20.8 ± 1 km/h | 3.2 ± 1.5 km/h |
| Stiffness | 700 kN/m ± 20% | 1000 kN/m ± 20% |

| | | |
|---|---|---|
| Repair calculation | | |
| Labour | 2200.00 CHF | 250.00 CHF |
| Additional cost | CHF | |
| Painting | CHF | |
| Spare parts | CHF | |
| VAT 7.60 % | 609.15 CHF | 138.55 CHF |
| Grand Total | 8624.55 CHF | 1961.60 CHF |

$$\Delta v_x = \int_{t_0}^{t_E} a_x dt$$

$$dt = t_E - t_0$$

$$k = \frac{v_2' - v_1'}{v_{K1} - v_{K2}}$$

$$\Delta v' = v_2' - v_1' = (v_{K2} + \Delta v_{x2}) - (v_{K1} + \Delta v_{x1})$$

$t_E$: end time of collision

HS 01 bis HS 73 (Series I through IV)
point in time when the longitudinal accelerations of both vehicles fall below 5 m/s² (without braking deceleration) or zero crossing of one of the two accelerations

HS 74 ff. (starting from Series V)
The following rule to calculate the impact time duration was introduced:
If the acceleration-time graph crosses zero before 95% of the maximum change in velocity Δv is reached*, this zero-crossing will not be regarded as the end time. Δv will then be taken as the maximum value reached before 250ms have elapsed.

*until HS134 (Series X), Δv refers to the change in velocity in the longitudinal direction, for HS135 ff. the resulting change in velocity is taken.

$t_0$: beginning of collision

point in time when the two vehicles touch (defined by contact trigger switch).

* : measured according toSAE J211 (± 3%)
** : calculated according toSAE J211 (± 3%)
*** : optical speed measurement(± 1%)

VALID FOR ALL TESTS WITH NUMBERS HS-XX

## Rear-end collision 100% 0° braked — Daten

Deformation energy ($W_{Def\ Ges}$)
Energy Equivalent Speed (EES)
vehicle stiffness c

| | | | | |
|---|---|---|---|---|
| Vehicles | stossend | | gestossen | |
| Make and Model | Daewoo Matiz | | Subaru Outback | |
| Type | 0.8i 5 T | | WD 5 Türen | |
| Frame number | KLA 4M 11C D | | LUA 5G 022 957 | |
| Year (first registration) | 07/20 | | 10/2004 | |
| Mileage | 29100 | | 7350 km | |
| Test weight | 952 kg | | 1704.5 kg | |
| Wheel weights FL FR | 286.5 kg | 280.5 kg | 494 kg | 448.5 kg |
| Wheel weights RL RR | 198 kg | 187 kg | 387.5 kg | 374.5 kg |
| Tyres | 155/65 R13 | 2.1 bar | 215/55 R17 | 2.2 bar |
| Brake action | 0.4 s vor Kollision; 7.3 m/s² | | - | |
| Remarks | - | | - | |

Factor for number of wheels

$J_{VV\ Rad}$: The momentum of inertia J of the wheels is determined experimentally

$$\Delta v_x = \int_{t_0}^{t_E} a_x \, dt$$

| | | | | |
|---|---|---|---|---|
| Velocities | | | | |
| $v_K$ | 26.0 km/h * | | 0 km/h | |
| $\Delta v_x$ | -20.7 km/h ** | | 9.8 km/h *** | |
| $\Delta v_y$ | 1.0 km/h ** | | -0.2 km/h ** | |
| $\Delta v_z$ | 0.3 km/h ** | | | |
| $\Delta v_{Res}$ | 20.8 km/h ** | | | |

η: vehicle-related percentage of the total deformation energy (explanation p. 18ff)

$$E_{B1} = \frac{1}{2} \cdot m_1 \cdot v_1^2$$

$$E_{B1} = \frac{1}{2} \cdot m_1 \cdot a_{Brems1} \cdot dt \cdot (v_{K1} + v'_1)$$

| | | | | | | |
|---|---|---|---|---|---|---|
| Accelerations | | | | | | |
| $a_{x\,max}$ / $a_{y\,max}$ / $a_{z\,max}$ | -14.3 g * | 3.5 g * | | | | |
| $a_{Res\,max}$ | 14.6 g * | | | 11.3 g * | | |
| $a_{x\,dt}$ / $a_{y\,dt}$ / $a_{z\,dt}$ | -5.6 g * | 0.3 g * | 0.1 g * | 2.6 g * | -0.1 g * | -0.4 g * |
| $a_{Res\,dt}$ | 5.6 g * | | | 2.6 g * | | |

$$EES_1 = 3.6 \cdot \sqrt{\frac{2 \cdot \eta \cdot W_{DefGes}}{m_1}}$$

$$W_{DefGes} = E_1 + E_2 - E_1' - E_2' - E_{B1}$$

| | |
|---|---|
| Impact ti | 104 ms |
| Impact fa | 0.17 ** / 4.5 km/h ** |

| | | |
|---|---|---|
| Total deformation energy $W_{Def\ Ges}$ | 16.6 kJ ± 10% | |
| Energy Equivalent Speed EES | 20.8 ± 1 km/h | 3.2 ± 1.5 km/h |
| Stiffness | 700 kN/m ± 20% | 1000 kN/m ± 20% |

tolerance range includes minimum and maximum values encountered during

| | | |
|---|---|---|
| Repai | | |
| Labou | 2200 | |
| Additi | 390 | |
| Painti | 1848 | |
| Spare parts | 3576 | |
| VAT 7.60 % | 609.15 CHF | 138.55 CHF |
| Grand | 5 CHF | 1961.60 CHF |

$$C_{1,2} = \frac{\max F_{def_lin1,2tj}}{\max s_{dyn1,2tj}} = \frac{(m_{1,2} \cdot a_{x1,2})_{lin,tj}}{\max \Delta s_{dyn,tj} \cdot \lambda_{1,2}}$$

tj → point in time of maximum dynamic deformation (cf. intrusion diagram $\Delta s_{dyn}$) or of maximum of the linearised force-deformation history

$F_{def_lin1,2tj}$ → Maximum of the linearised force-deformation history

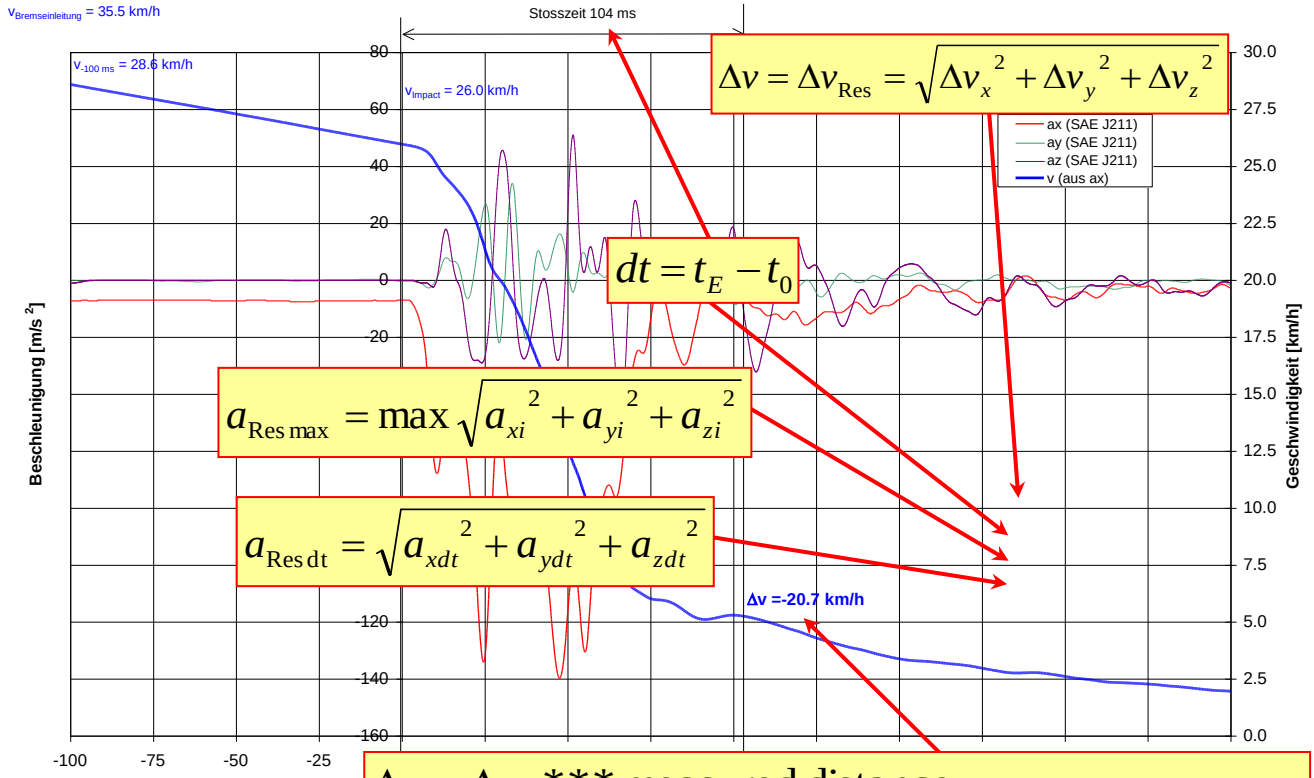
$\lambda_{1,2}$ → average distribution of the static deformation measurement target points (with / without bumper)

* :
** :
*** :

Valid only for HS 01 to HS 62

## Rear-end collision 100% 0° braked — Data SAE J211 Vehicle 1 and 2

**HS33 stossendes Fahrzeug: Daewoo Matiz**




$$\Delta v = \Delta v_{Res} = \sqrt{\Delta v_x^{\,2} + \Delta v_y^{\,2} + \Delta v_z^{\,2}}$$

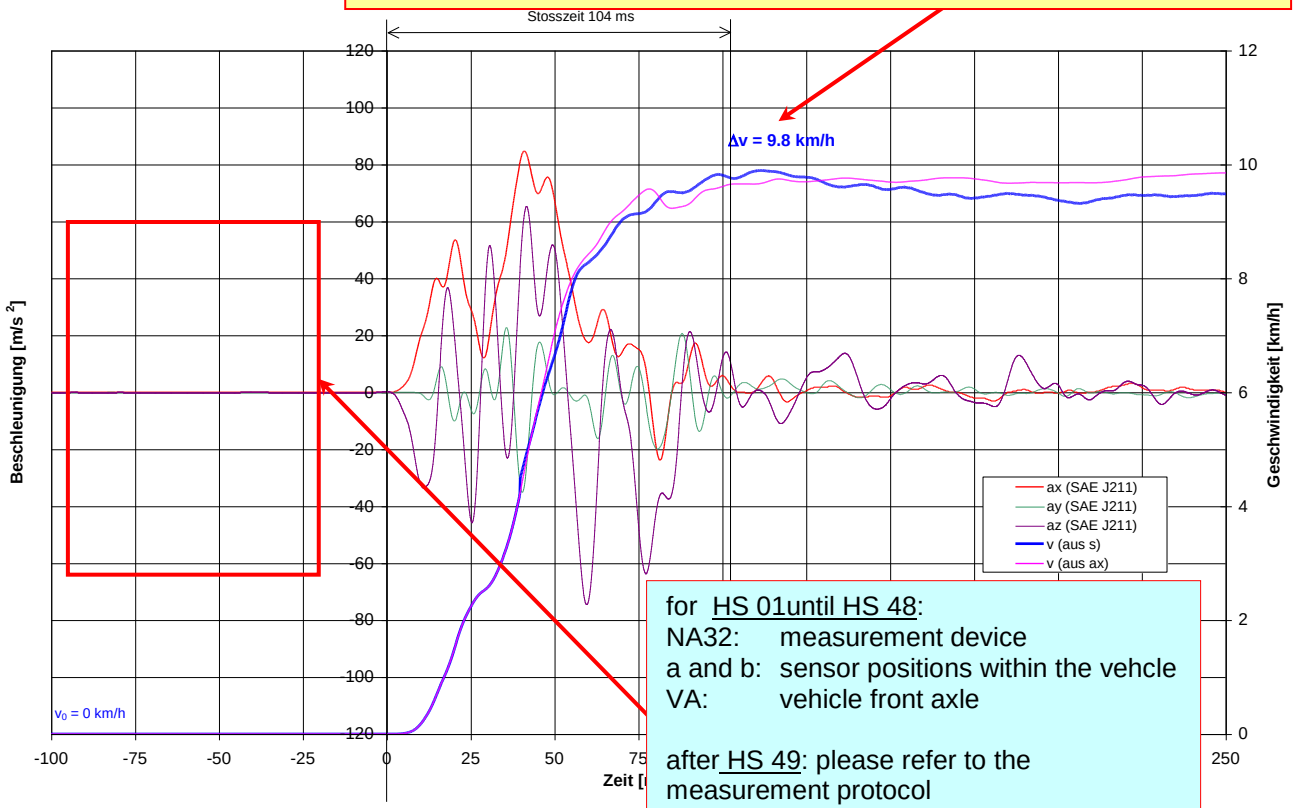
$$dt = t_E - t_0$$

$$a_{Res\,max} = \max\sqrt{a_{xi}^{\,2} + a_{yi}^{\,2} + a_{zi}^{\,2}}$$

$$a_{Res\,dt} = \sqrt{a_{xdt}^{\,2} + a_{ydt}^{\,2} + a_{zdt}^{\,2}}$$

$\Delta v = \Delta v_x$ *** measured distance

** calculated by integratin g accelerations




for HS 01until HS 48:
NA32: measurement device
a and b: sensor positions within the vehcle
VA: vehicle front axle

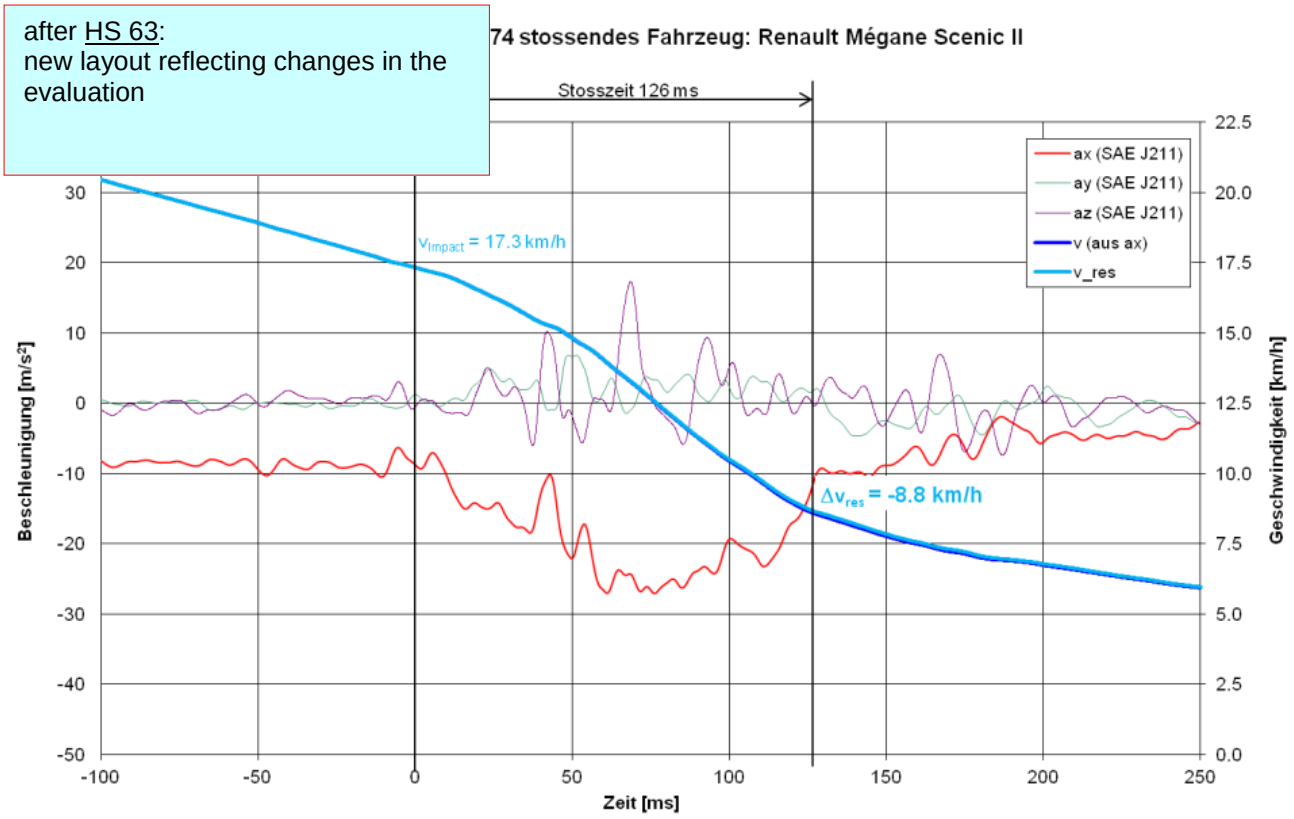
after HS 49: please refer to the measurement protocol

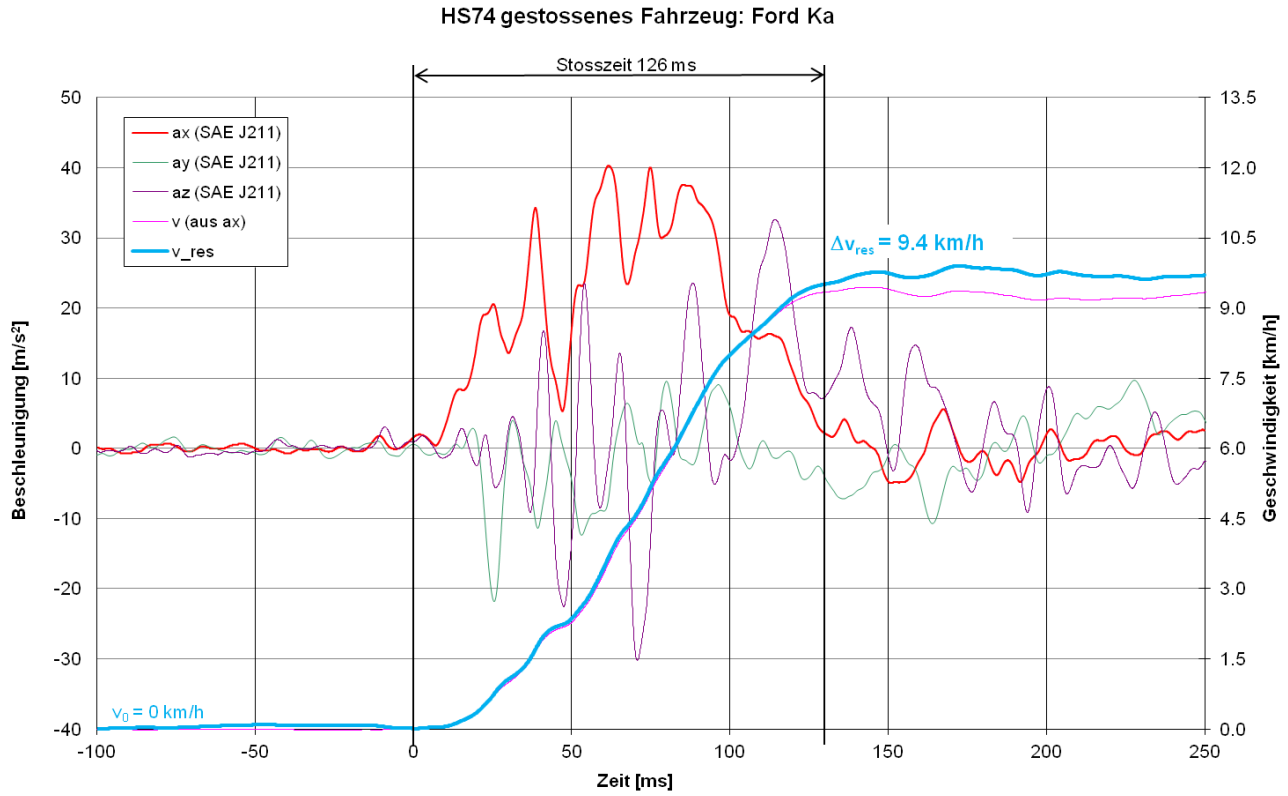
Measurement accuracy NA32 (SAE J211): ± 3%  Optical velocity measurement: ± 1%

Valid Only after HS 63

## Rear end collision 20% 0° braked — Data SAE J211 Vehicle 1 and 2

after HS 63:
new layout reflecting changes in the evaluation



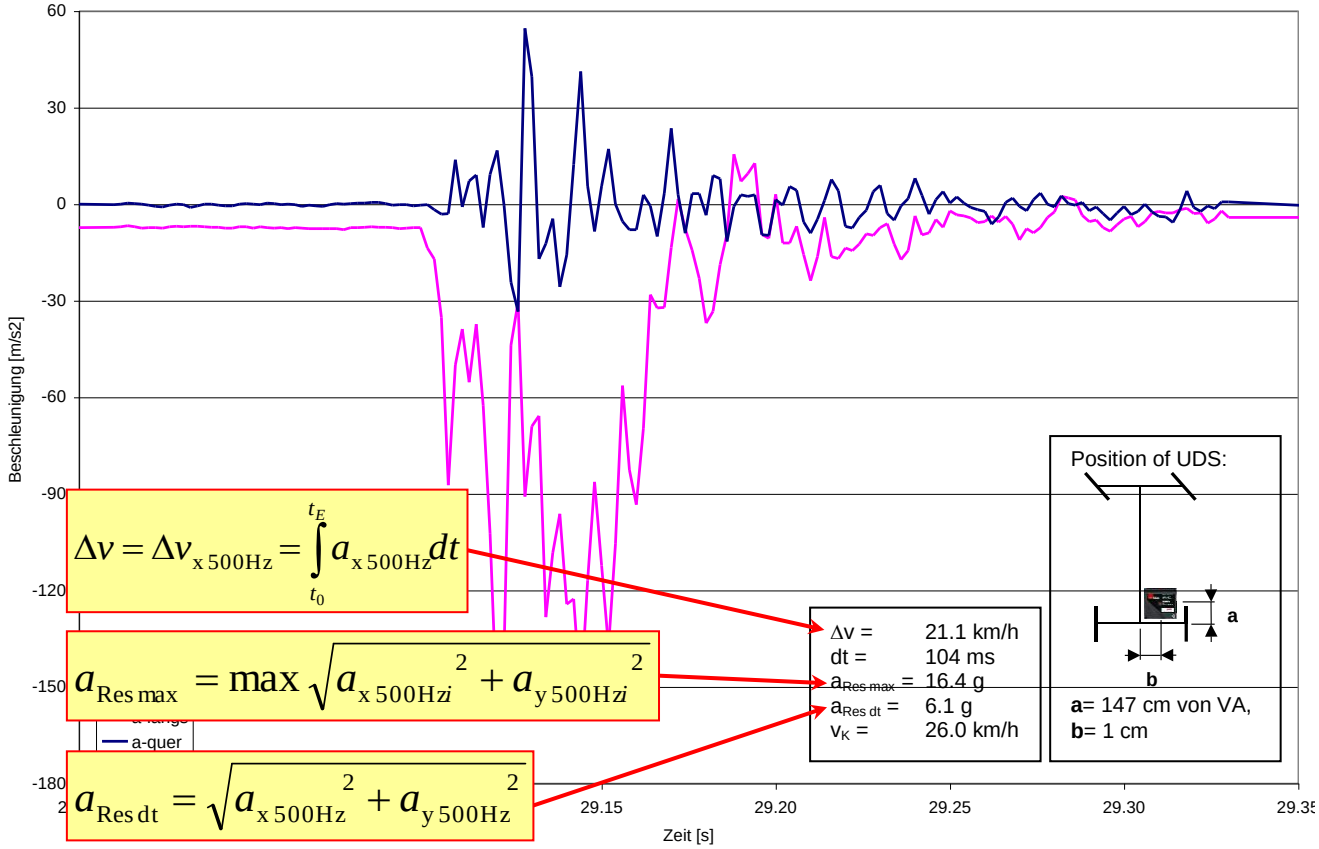




Measurement accuracy NA32 (SAE J211): ± 3% Optical speed measurement : ± 1%

VALID ONLY FOR HS 01 - HS 48

## Rear-end collision 100% 0° braked — Data 500Hz Vehicle 1 and 2

Vehicle 1: Daewoo Matiz

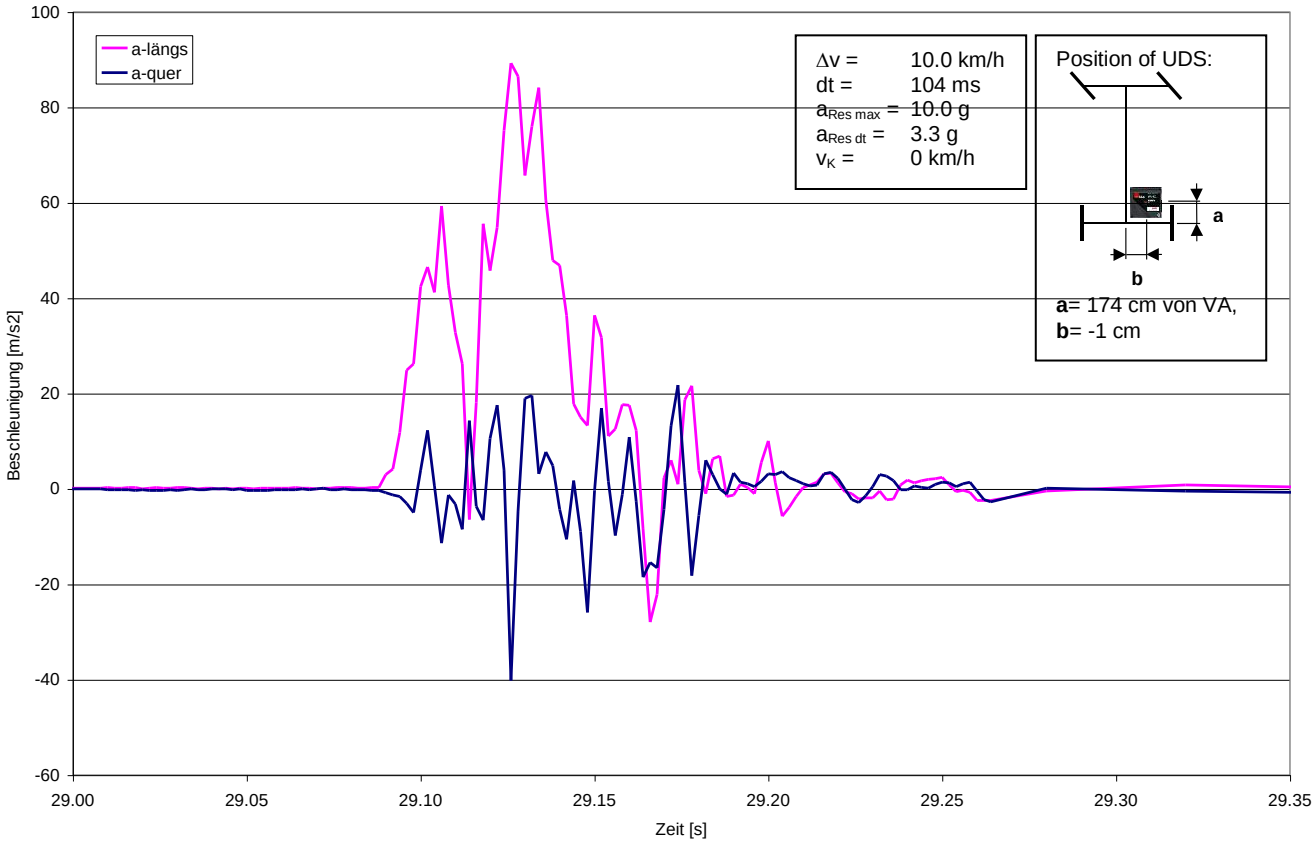



$$\Delta v = \Delta v_{x\,500\mathrm{Hz}} = \int_{t_0}^{t_E} a_{x\,500\mathrm{Hz}}\,dt$$

$$a_{\mathrm{Res\,max}} = \max\sqrt{a_{x\,500\mathrm{Hz}i}^{\;2} + a_{y\,500\mathrm{Hz}i}^{\;2}}$$

$$a_{\mathrm{Res\,dt}} = \sqrt{a_{x\,500\mathrm{Hz}}^{\;2} + a_{y\,500\mathrm{Hz}}^{\;2}}$$

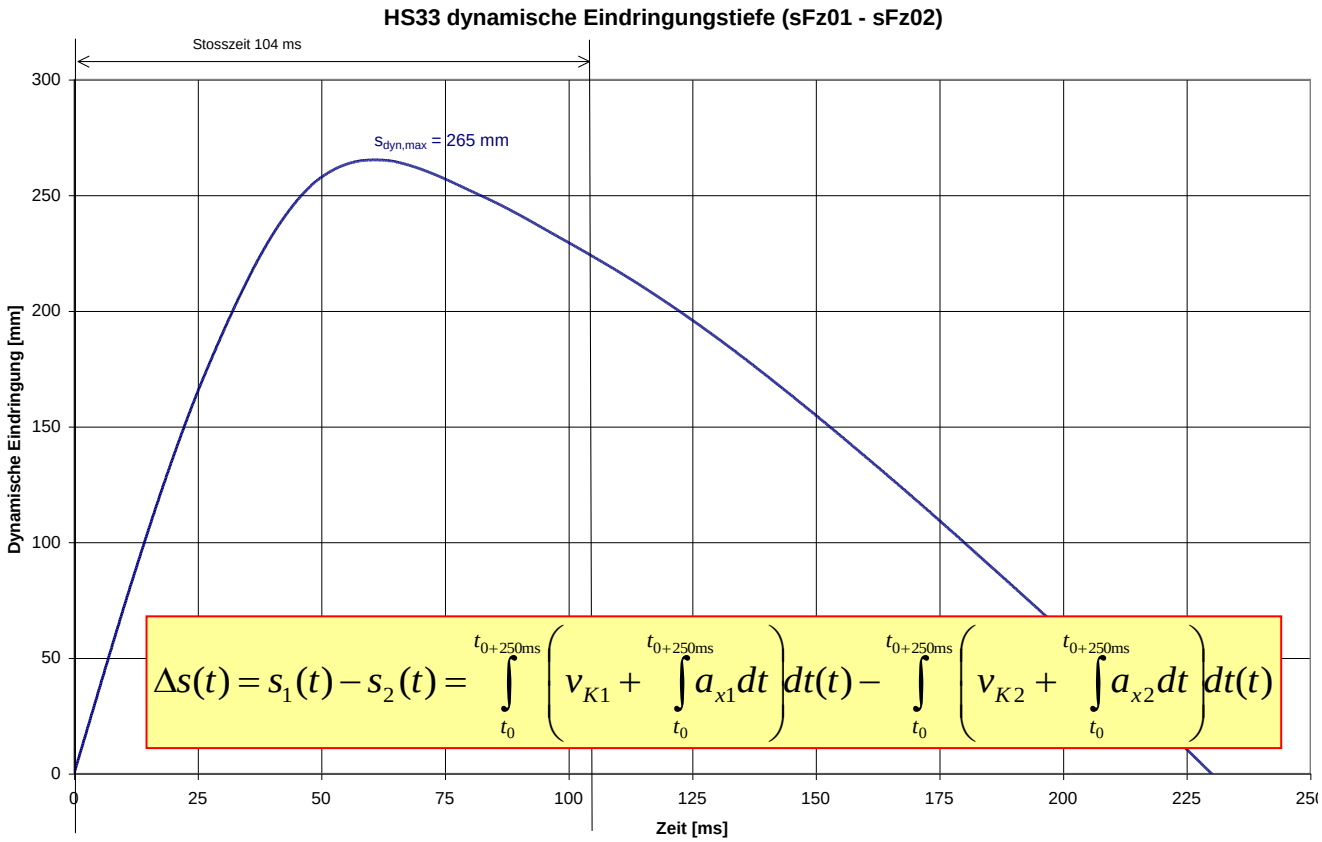
Vehicle 2: Subaru Outback



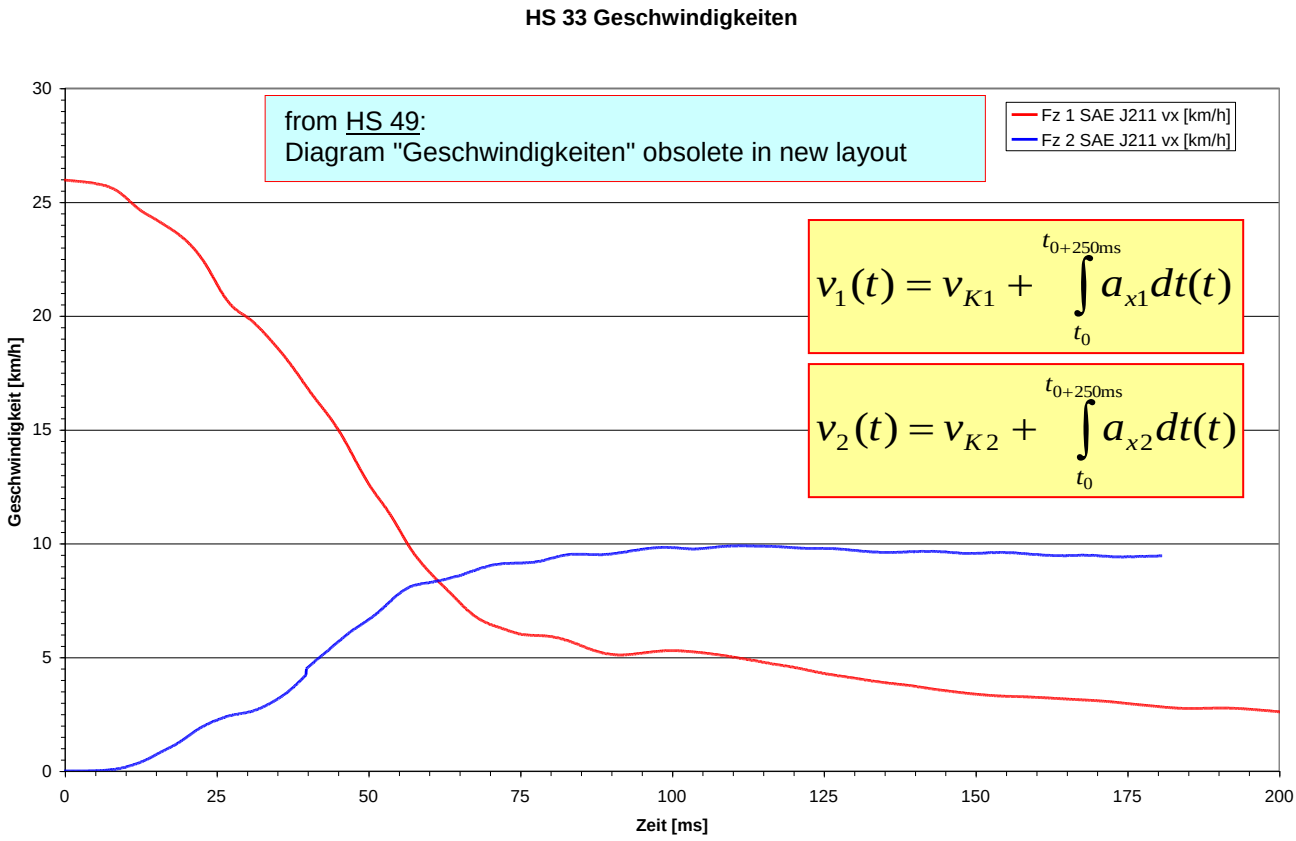

Measurement accuracy electronic data recorder UDS: ± 10%

## Rear-end collision 100% 0° braked — Dynamic Deformation

Dynamic intrusion of both vehicles




$$\Delta s(t) = s_1(t) - s_2(t) = \int_{t_0}^{t_{0+250ms}} \left( v_{K1} + \int_{t_0}^{t_{0+250ms}} a_{x1} dt \right) dt(t) - \int_{t_0}^{t_{0+250ms}} \left( v_{K2} + \int_{t_0}^{t_{0+250ms}} a_{x2} dt \right) dt(t)$$



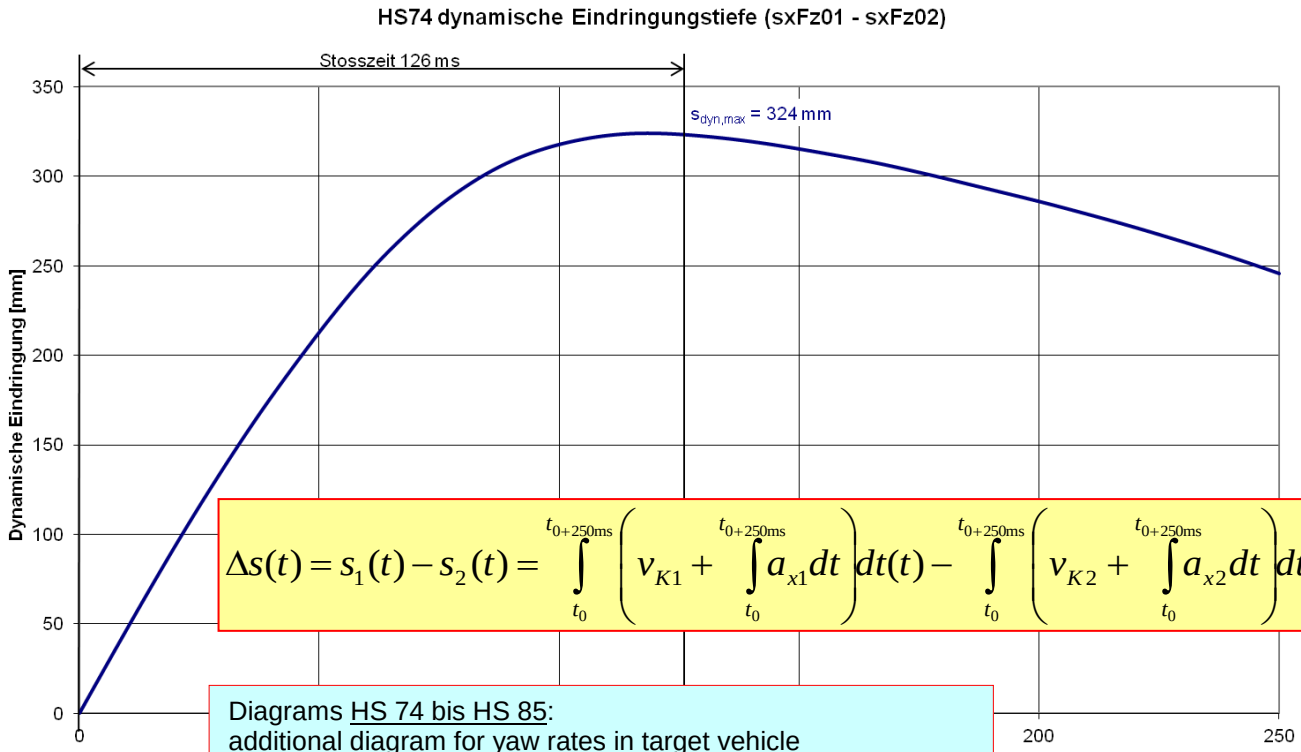

$$v_1(t) = v_{K1} + \int_{t_0}^{t_{0+250ms}} a_{x1} dt(t)$$

$$v_2(t) = v_{K2} + \int_{t_0}^{t_{0+250ms}} a_{x2} dt(t)$$

NOT VALID FOR HS 74 - HS85

## Rear end collision 20% 0° braked — Dynamic Deformation

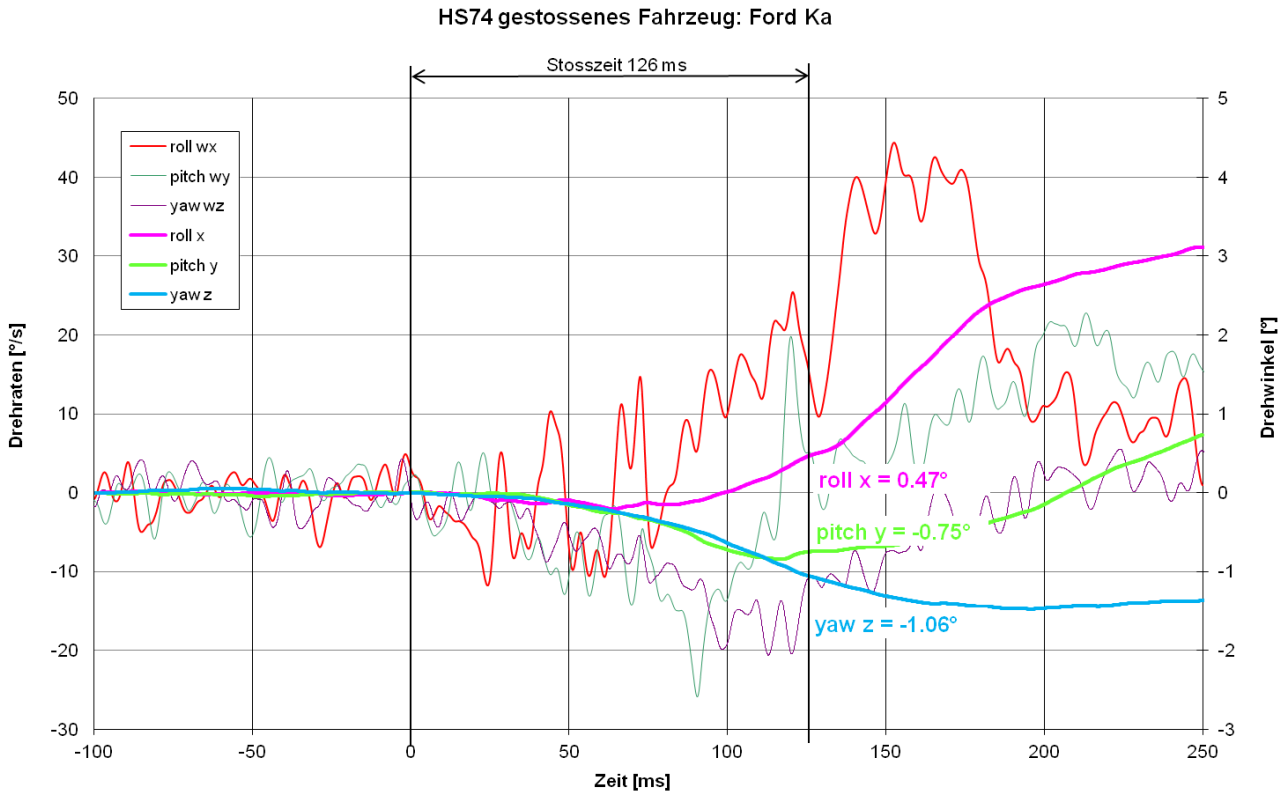
Dynamic intrusion of both vehicles




$$\Delta s(t) = s_1(t) - s_2(t) = \int_{t_0}^{t_{0+250ms}} \left( v_{K1} + \int_{t_0}^{t_{0+250ms}} a_{x1} dt \right) dt(t) - \int_{t_0}^{t_{0+250ms}} \left( v_{K2} + \int_{t_0}^{t_{0+250ms}} a_{x2} dt \right) dt(t)$$

Diagrams HS 74 bis HS 85:
additional diagram for yaw rates in target vehicle

Rotational velocity / rotating angle of the struck vehicle



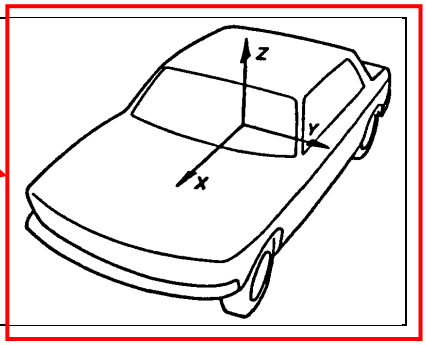

NUR GÜLTIG FÜR HS 74 bis HS 85

NUR GÜLTIG FÜR HS 01 bis HS 48

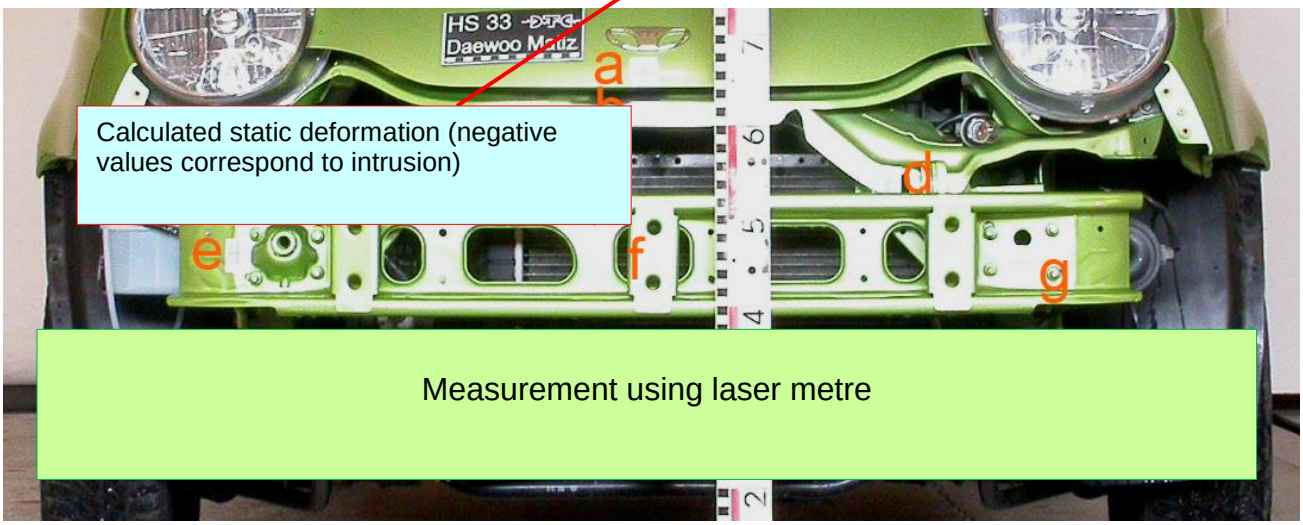
## Rear-end collision 100% 0° braked — Static Deformation Vehicle 1

Orientation of co-ordinate system

Pre-crash picture including measurement targets and designations of the measured points



| Deformation [mm] | a | b | c | d | e | f | g | h | i | j |
|---|---|---|---|---|---|---|---|---|---|---|
| x-Axis | -84 | -47 | -38 | -43 | -21 | -21 | | | | |
| y-Axis | -2 | 0 | 0 | 0 | -2 | -2 | | | | |
| z-Axis | 27 | 15 | 12 | 15 | 17 | 17 | | | | |




Calculated static deformation (negative values correspond to intrusion)

Measurement using laser metre

| Deformation [mm] | a | b | c | d | e | f | g | h | i | j |
|---|---|---|---|---|---|---|---|---|---|---|
| x-Axis | -83 | -90 | -118 | -237 | -31 | -107 | -2 | -1 | -1 | |
| y-Axis | 3 | -3 | 8 | 3 | 15 | 14 | 10 | 12 | 5 | |
| z-Axis | 28 | 25 | -10 | 29 | 20 | | | | -1 | |

Manufacturer's tolerance specification

Measurement accuracy Laser: ± 3 mm

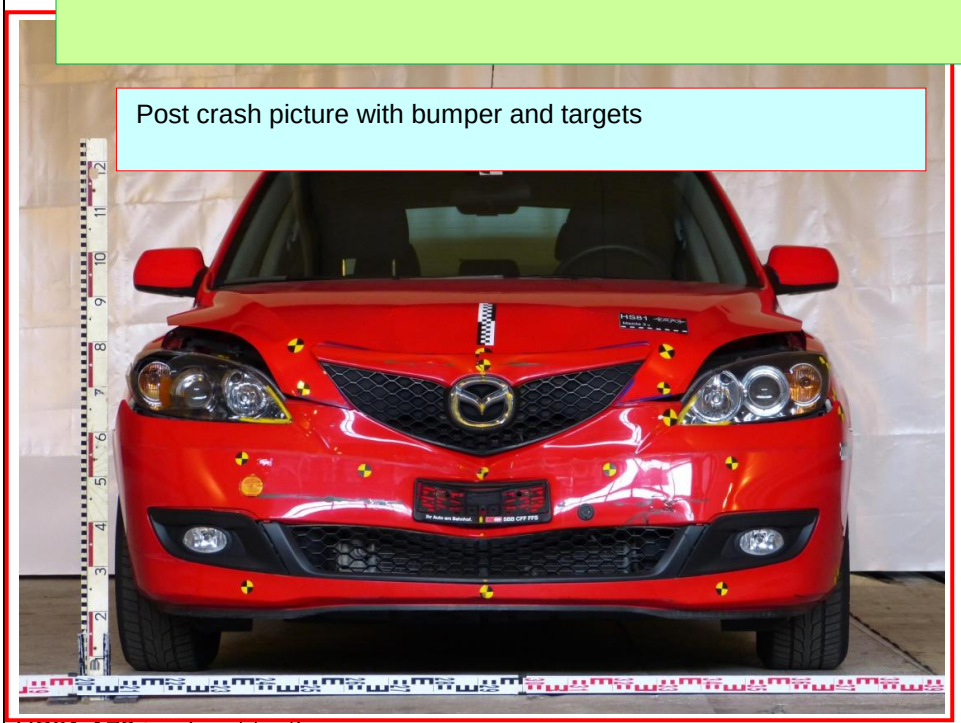
NUR GÜLTIG FÜR ab HS 49

**Rear-end collision 100% 0° braked** **Static Deformation Vehicle 1**

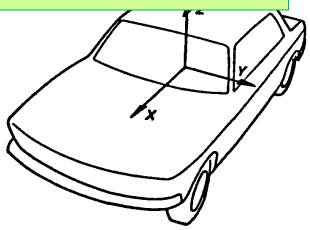
Stati

3D-Laser scans

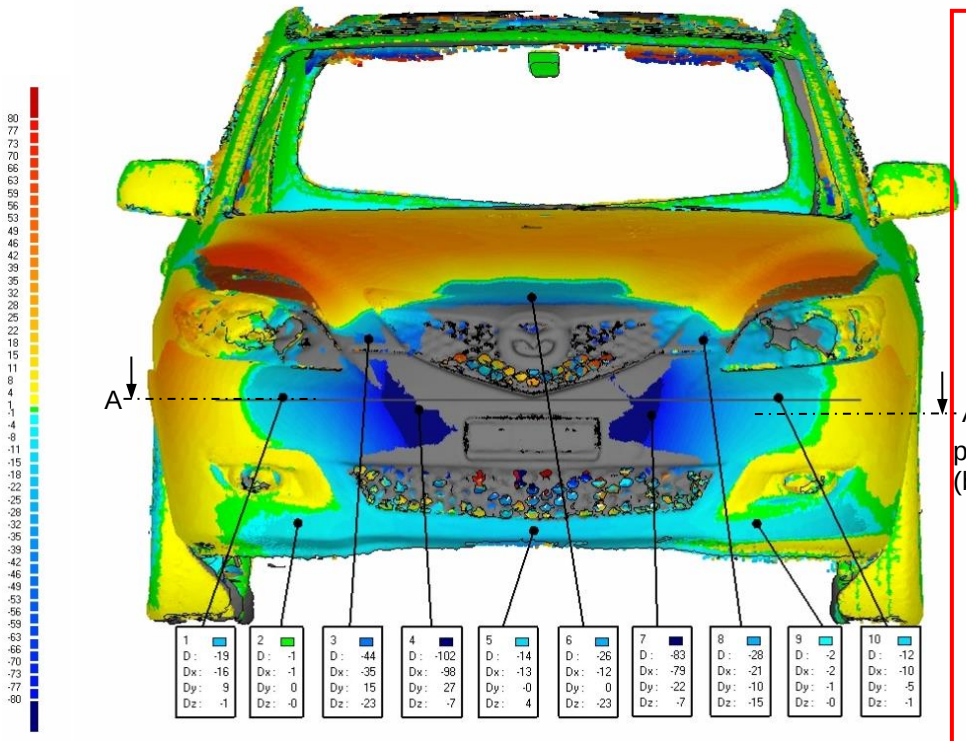
Post crash picture with bumper and targets

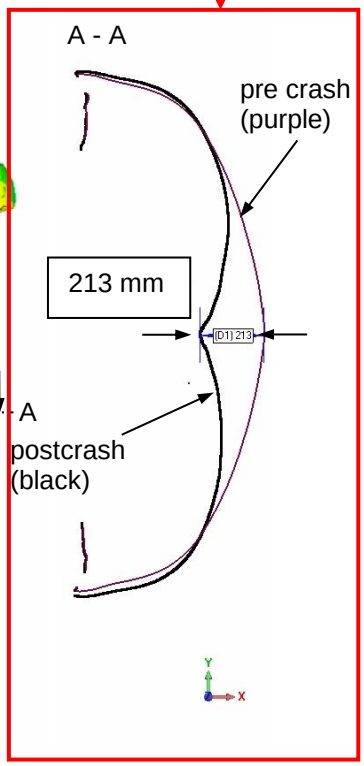


HS81-173.jpg (post test)




Additional section drawings at particular deformation depth



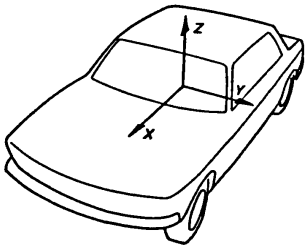

Additional view: section at the height of the bumper support member (z = 530 mm)
Measurement accuracy 3D-Laser: ± 3 mm

NUR GÜLTIG FÜR ab HS 49

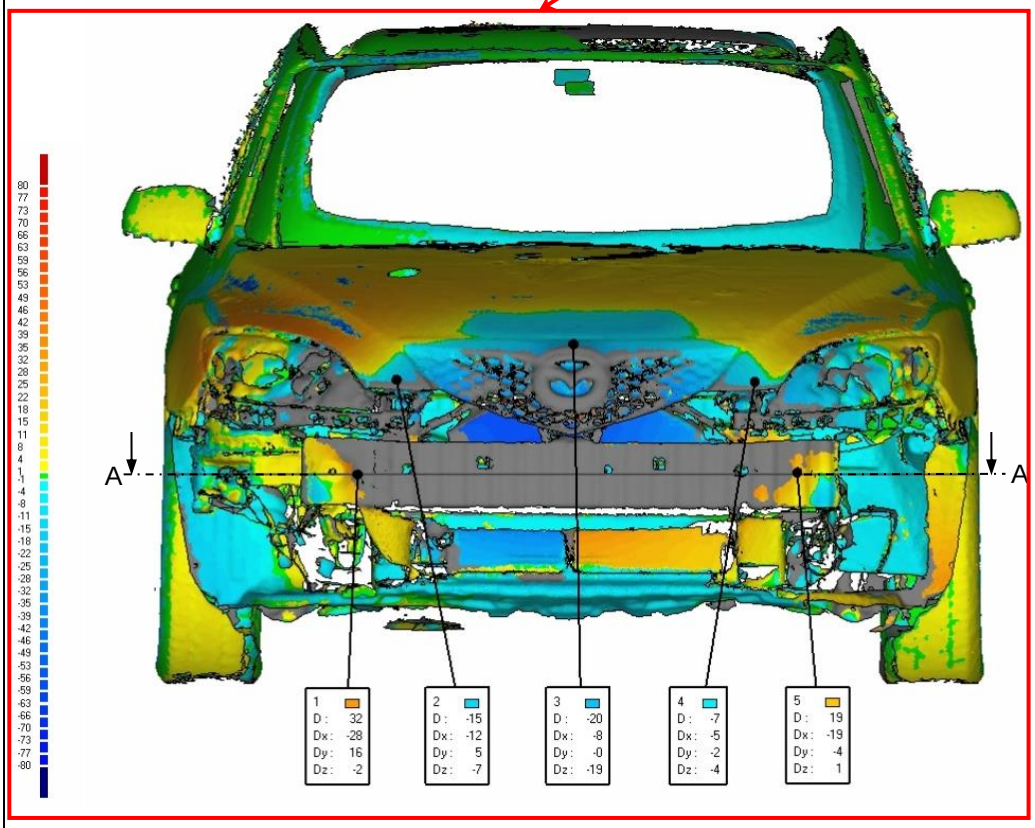
## Rear-end collision 100% 0° braked — Static Deformation Vehicle 1

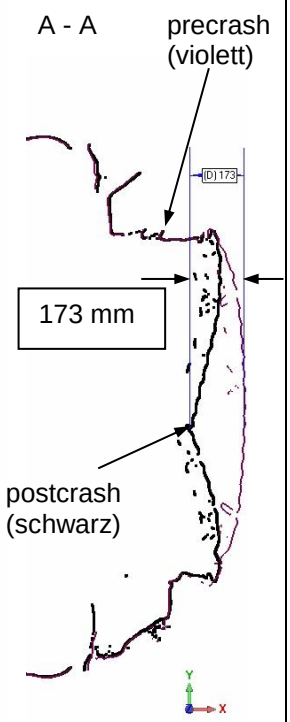
Static Deformation Vehicle 1 without bumper

HS81-183.jpg (post test)




false colour picture, superposition of pre- and post-crash scans. Colour scale left, deformation depths at target points




Note: the measurement targets on the bonnet are taken from the model including bumper. Additional view: section at the height of the bumper support member (z = 460 mm)
Measurement accuracy 3D-Laser: ± 3 mm

## Changes in the test data analysis procedure

The test data analysis procedure was adapted several times. The most important changes are listed below:

- Starting with HS 49, no DER (UDS 500Hz) was installed in the vehicles. A second measurement system (20 kHz sampling rate) was used instead, for redundancy and verification of the measurements..
- Starting with HS 63:
  - The vehicle's velocity was calculated and plotted using the acceleration ($a_x$) and vectorial addition ($v_x + v_y + v_z$).
  - The calculated change in velocity (delta-v) of the target vehicle was verified using displacement measurements and video analysis.
- Starting with HS 74 until HS 85, rotational velocities of the target vehicles were measured additionally, and plotted together with the resulting rotation angles.

# Rating standards for test data quality, also applicable for reconstruction tests

The rating standards for the tests defined below supply information (using a "star rating) on the quality and quantity of the available data. The higher the number of stars, the greater the accuracy and the amount of measurement data and supplementary information. A five-star-test is, in this sense, a gold standard. Depending on the circumstances, precise and useful accident analyses can also be performed using test results with a lower rating.

★☆☆☆☆ Minimal standard

★★★★★ Maximal standard

After the third series (HS 13) the tests attained five star ratings. We have been unable to locate reconstruction tests in Europe that were performed on a similar level. The standards thus define minimum requirements that are, in part, clearly surpassed.

## *5-star-test* ★★★★★

| | |
|---|---|
| Data acquisition: | Measurement data:<br>- According to **SAE J 211**<br>- $a_x$ and $a_y$ of both Vehicles<br>- Synchronised acquisition<br>- Redundant measurement of $\Delta v$ in the target vehicle (2 - fold)<br>Accuracy of measurement data:<br>± 3% for acceleration measurements<br>± 1% for velocity based on displacement measurement<br>± 10 kg vehicle total mass<br><br>Detailed description of vehicle: Make and model, frame number, model year<br><br>Measurement protocols: sensors, positioning, vehicle mass front and rear axle, tyres (dimension, type, state, pressure), mileage, fuel tank contents |
| Collision configuration: | Collision velocity of the bullet vehicle, braking condition of both vehicles (measured decelerations), overlap, collision angle given. |
| Photo documentation: | Pictures on the level of the damage zone:<br>- Vehicles pre- and post-test<br>- Vehicles with and without bumper cover<br>Views:<br>- Side view and 45° both sides<br>- Rear- and front view<br>- Top or bottom view<br>- Overview of damage (total view 45°)<br>Additional photosr:<br>- Real collision position<br>- Vehicles immediately after collision (rear- or front view, respectively)<br>- Damage pictures in detail |
| Film: | High speed video >= 500 fps. |
| Measurements of vehicles: | Target points relevant for the deformation are measured:<br>- pre- and post-test<br>- with and without bumper<br>accuracy ± 3 mm |
| Damage calculation: | e.g. using Audatex, auto-i-dat |
| Remarks: | Standard in our tests since HS 13 |

## *4-Star test* ★★★★☆

Data acquisition:

Measurement data:
- According to **SAE J 211**
- $a_x$ and $a_y$ of both Vehicles
- synchronised acquisition

Accuracy of measurement data:
± 6% for acceleration measurements and the velocity calculated by integrating accelerations
± 20 kg total vehicle mass

Detailed description of vehicle: Make and model, frame number, model year

Measurement protocols: sensors, positioning, vehicle mass front and rear axle, tyres (dimension, type, state, pressure), mileage, fuel tank contents

Collision configuration: Collision velocity of the bullet vehicle, braking condition of both vehicles (measured decelerations), overlap, collision angle given.

Photo documentation: Pictures on the level of the damage zone:
- Vehicles pre- and post-test
- Vehicles with and without bumper cover

Views:
- Side view and 45° both sides
- Rear- and front view
- Top or bottom view
- Overview of damage (total view 45°)

Additional photos:
- Real collision position
- Vehicles immediately after collision (rear- or front view, respectively)
- Damage pictures in detail

Film: High speed video >= 500 fps.

Measurements of vehicles: Target points relevant for the deformation are measured:
- pre- and post-test
- with and without bumper

accuracy ± 5 mm

Damage calculation: -

Remarks: Standard in our tests since HS 07 through HS 12

## *3-Star test* ★★★☆☆

Data acquisition:

Measurement data:
- According to **SAE J 211**
- $a_x$ and $a_y$ of both Vehicles
- synchronised acquisition

Accuracy of measurement data:
± 10% for acceleration measurements and the velocity calculated by integrating accelerations
± 30 kg total vehicle mass

Detailed description of vehicle: Make and model, frame number, model year

Measurement protocols: sensors, positioning, vehicle mass front and rear axle, tyres (dimension, type, state, pressure), mileage, fuel tank contents

Data acquisition:

Measurement data:
- $a_x$ of both Vehicles
- 250 Hz sampling frequency

Accuracy of measurement data:
± 10% for acceleration measurements and the velocity calculated by integrating accelerations
± 30 kg total vehicle mass

Detailed description of vehicle: Make and model, frame number, model year

Measurement protocols: total mass, tyres (dimension, pressure)

Collision configuration: braking condition of both vehicles (measured decelerations), overlap, collision angle given

Photo documentation: Pictures on the level of the damage zone:
- Vehicles pre- and post-test

Views:

| | |
|---|---|
| | - Side view and 45° both sides<br>- Rear- and front view<br>- Overview of damage (total view 45°)<br>Additional photos:<br>- Real collision position<br>- Vehicles immediately after collision (rear- or front view, respectively)<br>- Damage pictures in detail |
| Film: | Real-time (25 / 30 fps) video |
| Measurements of vehicles: | Target points relevant for the deformation are measured:<br>- pre- and post-test<br>accuracy ± 10 mm |
| Damage calculation: | - |
| Remark: | Standard in our tests HS 01 through HS 06, and some tests in the database that were acquired from other sources. |

## *2-Star test* ★★☆☆☆

| | |
|---|---|
| Data acquisition: | Measurement data: $a_x$ of both Vehicles<br>250 Hz Aufnahmefrequenz<br><br>Accuracy of measurement data:<br>± 10% for acceleration measurements and the velocity calculated by integrating accelerations<br>± 50 kg total vehicle mass<br><br>Detailed description of vehicle: Make and model, model year<br><br>Measurement protocols: total mass of vehicles |
| Collision configuration: | Overlap, collision angle |
| Photo documentation: | Pictures on the level of the damage zone:<br>- Vehicles pre and post-crash<br>Views:<br>- side view, 45° both sides<br>- Rear / Front view respectively<br>- Damage overview picture (45°) |
| Film: | - |
| Vermessung der Fz: | - |
| Damage calculation: | - |
| Remarks: | Normal standard of acquired tests |

## *1-Stern-Versuch* ★☆☆☆☆

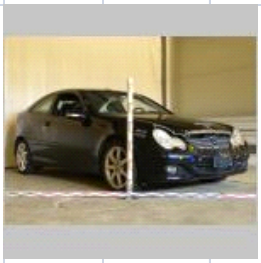
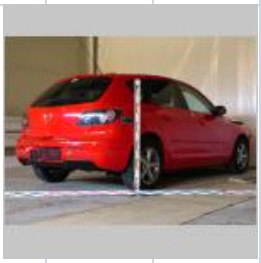
| | |
|---|---|
| Data acquisition: | Measurement data: $a_x$ target vehicle<br>100 Hz recording frequency<br>Measurement data accuracy:<br>± 15% for acceleration measurements and the velocity integrated thereof<br><br>Vehicle description: make and model<br><br>Vehicle total mass (including payload) |
| Collision configuration: | - |
| Photo documentation: | Vehicle pictures, unspecified |
| Film: | - |
| Vermessung der Fz: | - |
| Damage calculation: | - |
| Remarks: | - |

# EES determination (Energy Equivalent Speed)

The energy equivalent speed (EES) cannot be determined directly by e.g. measurement data. In order to supply these values, which are important for accident reconstruction, we have developed the following procedure:

- Totale Deformation energy: the total (combined) deformation energy can be calculated from measurement data..
- Primary EES distribution:
  Five accident reconstructionists estimate the energy distribution on the two vehicles independently.
- Secondary EES distribution:
  The same reconstructionists are supplied with the results of the other participants. The reconstructionists then may revise their judgement (percentage distribution of energy onto the two vehicles).
- EES:
  The average of all secondary distributions are included in the documentation.
- EES tolerance:
  The documentation also shows a tolerance value, corresponding to the maximum absolute deviation between mean value and a single result. Its minimum value will be 1 km/h in any case.

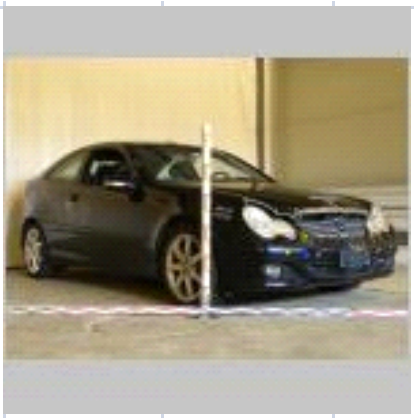
Input screen for the EES distribution, example HS 82:

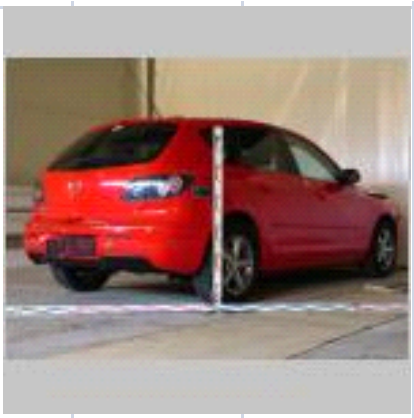



| Mercedes C-Klasse Coupe | | Mazda 3 | | | |
|---|---|---|---|---|---|
| | | stossend | | gestossen | |
| | | vor | nach | vor | nach |
| Masse | m | 1571.5 kg | | 1368.0 kg | |
| Kollisionsgeschwindigkeit | $v_K$ v' | 17.1 km/h | 6.6 km/h | 0.0 km/h | 9.3 km/h |
| Geschwindigkeitsänderung | Δvx | -10.5 km/h | | 9.3 km/h | |
| Kollisionsgeschwindigkeit | $v_K$ | 4.75 | 1.83 | 0.00 | 2.58 |
| Trägheitsmoment Rad | $J_{xx\ Rad}$ | 1.8 kgm2 | | 1.8 kgm2 | |
| Felgengrösse | D | 17 " | | 15 " | |
| Reifenbreite | b | 225 mm | | 195 mm | |
| Reifenhöhe | h | 45 % | | 65 % | |
| Radius aussen | $r_{A\ Rad}$ | 0.317 | 0.317 | 0.317 | 0.317 |
| Winkelgeschwindigkeit | $\omega_{Rad}$ | 14.98 rad/s | 5.78 rad/s | 0.00 rad/s | 8.14 rad/s |
| Rotationsenergie pro Rad | $E_{Rot\ 1\ Rad}$ | 202 J | 30 J | 0 J | 60 J |
| Rotationsenergie 4 Räder | $E_{Rot\ 4\ Räder}$ | 808 J | 120 J | 0 J | 239 J |
| Kinetische Energie | $E_{kin}$ | 17728 J | 2641 J | 0 J | 4565 J |
| Energie Total | $E_{Total}$ | 18536 J | 2761 J | 0 J | 4803 J |
| Bremsverzögerung | $a_{Brems}$ | 5.4 m/s2 | | 0 m/s2 | |
| Stosszeit | dt | 0.136 s | | | |
| Bremsenergie | $E_{Brems}$ | 3799 J | | 0 J | |
| Gesamte Deformationsenergie | $W_{Def\ Ges}$ | **7172 J** | | | |
| Trenngeschwindigkeit | Δv' | 2.7 km/h | | | |
| Stossfaktor | k | 0.16 | | | |
| Deformationstiefe | $s_{Def}$ | | | | |
| Energieaufteilung prozentual | $E_{Def\ proz}$ | 50.0 % | | 50.0 % | |
| E Aufteilung | $E_{Def}$ | 3586 J | | 3586 J | |
| Energy Equivalent Speed | EES | **7.7 km/h** | | **8.2 km/h** | |

| | | | | | |
|---|---|---|---|---|---|
| Impuls linear | $p_{Lin}$ | 7465 kgm/s | 2881 kgm/s | 0 kgm/s | 3534 kgm/s |
| Impuls rot. (4 Räder) | $p_{Rot\ 4\ Räder}$ | 108 kgm/s | 42 kgm/s | 0 kgm/s | 59 kgm/s |
| Impulsverlust Bremsung | $p_{Brems}$ | 1154 kgm/s | | 0 kgm/s | |
| Impuls total vor / nach | $p_{Total}$ | 7572 kgm/s | | 7669 kgm/s | |
| Impulsdifferenz | Δp | **-97 kgm/s** | | **-1.3 %** | |

Pictures of the crash configuration and the two vehicles post-crash, make and model of the cars:





| Mercedes C-Klasse Coupe | Mazda 3 |
|---|---|

The total deformation energy is calculated using:
Kinetic energy (vehicle mass and velocities), rotational energy of the wheels, and braking energy.

| | | stossend | | gestossen | |
|---|---|---|---|---|---|
| | | vor | nach | vor | nach |
| Masse | m | 1571.5 kg | | 1368.0 kg | |
| Kollisionsgeschwindigkeit | $v_K$ v' | 17.1 km/h | 6.6 km/h | 0.0 km/h | 9.3 km/h |
| Geschwindigkeitsänderung | Δvx | -10.5 km/h | | 9.3 km/h | |
| Kollisionsgeschwindigkeit | $v_K$ | 4.75 | 1.83 | 0.00 | 2.58 |
| Trägheitsmoment Rad | $J_{vv\ Rad}$ | 1.8 kgm2 | | 1.8 kgm2 | |
| Felgengrösse | D | 17 " | | 15 " | |
| Reifenbreite | b | 225 mm | | 195 mm | |
| Reifenhöhe | h | 45 % | | 65 % | |
| Radius aussen | $r_{A\ Rad}$ | 0.317 | 0.317 | 0.317 | 0.317 |
| Winkelgeschwindigkeit | $\omega_{Rad}$ | 14.98 rad/s | 5.78 rad/s | 0.00 rad/s | 8.14 rad/s |
| Rotationsenergie pro Rad | $E_{Rot\ 1\ Rad}$ | 202 J | 30 J | 0 J | 60 J |
| Rotationsenergie 4 Räder | $E_{Rot\ 4\ Räder}$ | 808 J | 120 J | 0 J | 239 J |
| Kinetische Energie | $E_{kin}$ | 17728 J | 2641 J | 0 J | 4565 J |
| Energie Total | $E_{Total}$ | 18536 J | 2761 J | 0 J | 4803 J |
| Bremsverzögerung | $a_{Brems}$ | 5.4 m/s2 | | 0 m/s2 | |
| Stosszeit | dt | 0.136 s | | | |
| Bremsenergie | $E_{Brems}$ | 3799 J | | 0 J | |
| Gesamte Deformationsenergie | $W_{Def\ Ges}$ | **7172 J** | | | |
| Trenngeschwindigkeit | Δv' | 2.7 km/h | | | |
| Stossfaktor | k | 0.16 | | | |

Momentum calculation as a double check:

| | | | | | |
|---|---|---|---|---|---|
| Impuls linear | $p_{Lin}$ | 7465 kgm/s | 2881 kgm/s | 0 kgm/s | 3534 kgm/s |
| Impuls rot. (4 Räder) | $p_{Rot\ 4\ Räder}$ | 108 kgm/s | 42 kgm/s | 0 kgm/s | 59 kgm/s |
| Impulsverlust Bremsung | $p_{Brems}$ | 1154 kgm/s | | 0 kgm/s | |
| Impuls total vor / nach | $p_{Total}$ | 7572 kgm/s | | 7669 kgm/s | |
| Impulsdifferenz | $\Delta p$ | **-97 kgm/s** | | **-1.3 %** | |

The blue field („50%“) below allows for the input of the percentage of deformation energy attributed to the target vehicle. The percentage is estimated such that realistiv values for the two EES result. All data is at the reconstructionist’s disposal in order to verify the results.

| | | | |
|---|---|---|---|
| Gesamte Deformationsenergie | $W_{Def\ Ges}$ | **7172 J** | |
| Trenngeschwindigkeit | $\Delta v'$ | 2.7 km/h | |
| Stossfaktor | k | 0.16 | |
| Deformationstiefe | $s_{Def}$ | | |
| Energieaufteilung prozentual | $E_{Def\ proz}$ | 50.0 % | 50.0 % |
| E Aufteilung | $E_{Def}$ | 3586 J | 3586 J |
| Energy Equivalent Speed | EES | **7.7 km/h** | **8.2 km/h** |

Overview of the primary estimaton, seven participants, tests HS74-HS 82:

**Prozentuale Aufteilung der Deformationsenergie für die Versuche HS 74 bis HS 85**

| | Prozentualer Anteil der Deformationsenergie Fahrzeug1 | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Versuch | PS | MW | MR | TE | TK | PaS | AF | Min | Max | **Mittel alle [%]** | Mittel ohne Min und Max [%] | Abw. Mittel [%] | EES1 Min [km/h] | EES1 Max [km/h] | **EES1 Mittel [km/h]** | EES2 Min [km/h] | EES2 Max [km/h] | **EES2 Mittel [km/h]** |
| HS74 | **30** | 35 | 65 | 60 | **68** | 65 | 60 | 30 | 68 | **54.7** | 57.0 | 2.3 | 4.8 | 7.2 | **6.4** | 6.3 | 9.3 | **7.5** |
| HS75 | **55** | 70 | **75** | 60 | 62 | 60 | 65 | 55 | 75 | **63.9** | 63.4 | -0.5 | 11.5 | 13.5 | **12.4** | 6.0 | 8.1 | **7.3** |
| HS76 | 55 | 55 | 57 | 55 | **45** | 50 | **65** | 45 | 65 | **54.6** | 54.4 | -0.2 | 9.0 | 10.9 | **10.0** | 8.0 | 10.0 | **9.1** |
| HS77 | **55** | 45 | 45 | **30** | 40 | 50 | 53 | 30 | 55 | **45.4** | 46.6 | 1.2 | 6.0 | 8.2 | **7.4** | 7.4 | 9.2 | **8.1** |
| HS78 | 63 | **45** | 72 | **45** | **74** | 66 | 60 | 45 | 74 | **60.7** | 61.2 | 0.5 | 5.8 | 7.5 | **6.8** | 5.7 | 8.2 | **7.0** |
| HS79 | 25 | 25 | **48** | 25 | **22** | 25 | 40 | 22 | 48 | **30.0** | 28.0 | -2.0 | 4.3 | 6.4 | **5.1** | 8.4 | 10.3 | **9.8** |
| HS80 | **80** | **80** | **80** | **90** | 82 | **80** | 82 | 80 | 90 | **82.0** | 80.8 | -1.2 | 15.6 | 16.6 | **15.8** | 4.6 | 6.4 | **6.1** |
| HS81 | 85 | 75 | 80 | 85 | **90** | 85 | **68** | 68 | 90 | **81.1** | 82.0 | 0.9 | 11.9 | 13.7 | **13.0** | 4.2 | 7.6 | **5.8** |
| HS82 | 60 | 70 | **73** | **55** | 65 | 60 | 60 | 55 | 73 | **63.3** | 63.0 | -0.3 | 8.1 | 9.3 | **8.7** | 6.1 | 7.8 | **7.1** |
| HS83 | 85 | 75 | 83 | 80 | **63** | **87** | 75 | 63 | 87 | **78.3** | 79.6 | 1.3 | 10.1 | 11.8 | **11.2** | 4.7 | 7.9 | **6.1** |
| HS84 | **55** | 75 | 83 | **85** | 71 | **85** | 72 | 55 | 85 | **75.1** | 77.2 | 2.1 | 12.2 | 15.2 | **14.3** | 5.4 | 9.4 | **7.0** |
| HS85 | 30 | **40** | 32 | 25 | 31 | **20** | 32 | 20 | 40 | **30.0** | 30.0 | 0.0 | 4.3 | 6.0 | **5.2** | 8.5 | 9.8 | **9.2** |

| Differenz zwischen EES Min und Max | | | |
|---|---|---|---|
| **Diff < 1.0** | **1.1 < Diff < 1.5** | **1.6 < Diff < 2.0** | **2.1 < Diff** |

All participants receive the summary shown above, i.e. the estimations of the other participants are available next to one’s own.

Overview of the secondary estimation, HS74 - HS 82:

**Prozentuale Aufteilung der Deformationsenergie für die Versuche HS 74 bis HS 85**

Prozentualer Anteil der Deformationsenergie Fahrzeug1

| Versuch | PS | MW | MR | TE | TK | PaS | AF | Min | Max | **Mittel alle [%]** | Mittel ohne Min und Max [%] | Abw. Mittel [%] | EES1 Min [km/h] | EES1 Max [km/h] | **EES1 Mittel [km/h]** | EES2 Min [km/h] | EES2 Max [km/h] | **EES2 Mittel [km/h]** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HS74 | 40 | **35** | 65 | 60 | **68** | 65 | 60 | 35 | 68 | **56.1** | 58.0 | 1.9 | 5.2 | 7.2 | **6.5** | 6.3 | 9.0 | **7.4** |
| HS75 | **60** | **70** | **70** | **60** | 62 | **60** | 65 | 60 | 70 | **63.9** | 63.4 | -0.5 | 12.0 | 13.0 | **12.4** | 6.6 | 7.6 | **7.3** |
| HS76 | 55 | 55 | **57** | 55 | 55 | **50** | 55 | 50 | 57 | **54.6** | 55.0 | 0.4 | 9.5 | 10.2 | **10.0** | 8.8 | 9.5 | **9.1** |
| HS77 | 53 | 45 | 45 | **40** | **40** | 50 | **55** | 40 | 55 | **46.9** | 46.6 | -0.3 | 7.0 | 8.2 | **7.5** | 7.4 | 8.5 | **8.0** |
| HS78 | 63 | **55** | 72 | **55** | **74** | 66 | 60 | 55 | 74 | **63.6** | 63.2 | -0.4 | 6.4 | 7.5 | **6.9** | 5.7 | 7.5 | **6.7** |
| HS79 | 25 | 25 | **35** | 25 | **22** | 25 | 25 | 22 | 35 | **26.0** | 25.0 | -1.0 | 4.3 | 5.5 | **4.7** | 9.4 | 10.3 | **10.0** |
| HS80 | **80** | **80** | **80** | **90** | 82 | **80** | 82 | 80 | 90 | **82.0** | 80.8 | -1.2 | 15.6 | 16.6 | **15.8** | 4.6 | 6.4 | **6.1** |
| HS81 | 85 | **75** | 80 | 85 | **90** | 85 | 80 | 75 | 90 | **82.9** | 83.0 | 0.1 | 12.5 | 13.7 | **13.1** | 4.2 | 6.7 | **5.6** |
| HS82 | **60** | **70** | **70** | **55** | 65 | 60 | 60 | 55 | 70 | **62.9** | 63.0 | 0.1 | 8.1 | 9.1 | **8.6** | 6.4 | 7.8 | **7.1** |
| HS83 | **85** | **75** | 83 | 80 | **75** | **85** | **75** | 75 | 85 | **79.7** | 79.6 | -0.1 | 11.0 | 11.7 | **11.3** | 5.0 | 6.5 | **5.9** |
| HS84 | **71** | 75 | 83 | **85** | **71** | **85** | 72 | 71 | 85 | **77.4** | 77.2 | -0.2 | 13.9 | 15.2 | **14.5** | 5.4 | 7.5 | **6.6** |
| HS85 | 30 | **35** | 32 | **25** | 31 | **25** | 32 | 25 | 35 | **30.0** | 30.0 | 0.0 | 4.8 | 5.7 | **5.2** | 8.8 | 9.5 | **9.2** |

Differenz zwischen EES Min und Max

| | | | |
|---|---|---|---|
| **Diff < 1.0** | **1.1 < Diff < 1.5** | **1.6 < Diff < 2.0** | **2.1 < Diff** |

In test HS 82 this means (referring to the bullet vehicle) :
minimum value: 55%; maximum value 70%; average 62.9%

transformed into EES values, this means:

| Versuch | EES1 Min [km/h] | EES1 Max [km/h] | **EES1 Mittel [km/h]** | EES2 Min [km/h] | EES2 Max [km/h] | **EES2 Mittel [km/h]** |
|---|---|---|---|---|---|---|
| HS82 | 8.1 | 9.1 | **8.6** | 6.4 | 7.8 | **7.1** |

| | | |
|---|---|---|
| **1.1 < Diff < 1.5** | **1.6 < Diff < 2.0** | **2.1 < Diff** |

And the documentation is filled in as follows (HS 82):

Ein Mercedes C-Klasse Coupe fährt gebremst (5.4m/s²) einem Mazda 3 (ungebremst, kein Gang eingelegt) auf.

| | | |
|---|---|---|
| Crash Test Resultate | stossend | gestossen |
| Fahrzeug | Mercedes C-Klasse Coupe | Mazda 3 |
| Masse | 1571.5 kg | 1368 kg |
| Bremse | 5.4 m/s² | - |

| | | |
|---|---|---|
| Kollisionsgeschwindigkeit $v_K$ | 17.1 km/h * | 0 km/h |
| Geschwindigkeitsänderung $\Delta v_{Res}$ | 10.5 km/h ** | 9.3 km/h ** |

| | | |
|---|---|---|
| Maximale Beschleunigung $a_{Res\ max}$ | 9.9 g * | 10.7 g * |
| Durchschnittliche Beschleunigung $a_{Res\ dt}$ | 2.2 g * | 1.9 g * |

| | |
|---|---|
| Stosszeit dt | 136 ms * |
| Stossfaktor k / Trenngeschwindigkeit Δv' | 0.16 ** / 2.7 km/h ** |

| | | |
|---|---|---|
| Gesamte Deformationsenergie $W_{Def\ Ges}$ | 7.2 kJ ± 10% | |
| Energy Equivalent Speed EES | 8.6 ± 1 km/h | 7.1 ± 1 km/h |
| Steifigkeit | - | - |

| | | |
|---|---|---|
| Reparaturkalkulation gesamt | 10'099.15 CHF | 2'948.65 CHF |