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Road vehicles — Traffic accident analysis —

Part 2:
Guidelines for the use of impact severity measures

Véhicules routiers — Analyse des accidents de la circulation —

Partie 2: Lignes directrices pour l'utilisation des mesures de gravité des chocs

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 12353-2 was prepared by Technical Committee ISO/TC 22, *Road vehicles*, Subcommittee SC 12, *Passive safety crash protection systems*.

ISO 12353 consists of the following parts, under the general title *Road vehicles — Traffic accident analysis*:

— *Part 1: Vocabulary*

— *Part 2: Guidelines for the use of impact severity measures*

Introduction

Any considered approach to road safety requires some concept of *impact severity*, which is normally thought of as the physical violence of a vehicle crash.

A government or other regulatory body implementing traffic-calming measures looks for a reduction in the severity of impacts on the modified roads; similarly, in introducing vehicle crash test regulations, it needs to know how the impact severity of the test configuration compares with the severity of impacts occurring on public roads.

Vehicle manufacturers seeking to improve the crashworthiness of their products also require some definition of impact severity, since the design changes that work best to provide occupant protection at low speeds are not necessarily — or even usually — also the best at high speeds.

Researchers and other investigators of real accidents provide data and advice to governments, manufacturers and other interested parties, and are required to produce measures of impact severity based on the evidence available to them after a crash has occurred.

Impact severity focuses on the vehicle, not the vehicle occupant, and in this context it is conventional to distinguish *the first* from *the second* collision. Typically, in a crash that results in occupant injuries there is first a collision between the vehicle and some other object, such as another vehicle, tree, or post: this is referred to as the *first collision*. A very short time later, some part of the interior passenger compartment, usually including a restraint system, is loaded by the occupant: this is referred to as the *second collision*.

Although these two collisions are not the same, they are obviously closely related, as the first collision creates most of the relevant conditions for the second. Prominent among these conditions is the direction and rate of vehicle deceleration, and the magnitude and rate of passenger compartment deformation.

Impact severity pertains to the violence of the first collision, and therefore does not directly determine the injury outcome. This leaves it possible to speak of low severity impacts that result in high injury levels, and vice versa. Generally, however, for a particular impact configuration, greater impact severity is associated with more severe injuries. The final outcome of the crash depends on the characteristics of the injury-reducing measures used, the human kinematics and the tolerance of the human body itself.

Measures of impact severity tend to be vehicle speed, velocity, acceleration or crush parameters. Some are easier to assess than others, and some are more relevant than others in particular accident circumstances. For this reason, a variety of measures is widely used.

Even when the impact severity parameters taken under consideration are correlated to the injury outcome, they are not necessarily responsible for injuries in terms of a causal reason. Other factors can also contribute to injury causation.

A description of these parameters, the information required to calculate them, and the methods by which they are assessed are given in Annex A.

The model shown in Figure 1 is an attempt to subdivide the sequence between the initial dose (physical input) and the response, defined as injury consequences. The parameters above the upper horizontal line are part of the pre-crash phase and constitute factors such as how the vehicle and the occupant appear in normal traffic immediately before impact. The dose, defined as the input into the complete system that cannot be affected by the vehicle, is the closing velocity. The parameters listed between the two horizontal lines occur during the crash phase (as defined in ISO 12353-1).

A complex dose–response system such as a vehicle impact can be divided into several different subdose–response systems according to the question under study. The different subdose–response systems may be seen within or between the shaded areas in Figure 1. Some of the factors influencing the injury outcome are hidden in the dynamic sequence, such as dynamic deformations, occupant trajectory and contact speed, while others, such as contact areas, change of velocity and final deformations of the vehicle, can be reconstructed or measured. In some cases, the dose–response model used depends on what it is possible to observe, estimate or measure, meaning that substitutes for better measurements are often used.

Clause 4 of this document is related to response in terms of injury, and Clause 5 is related to the vehicle response (e.g. deformations or interior damage).

Road vehicles — Traffic accident analysis —

Part 2:
Guidelines for the use of impact severity measures

1 Scope

This part of ISO 12353 describes the suitability of various measures for the determination of impact severity in road vehicle accidents. It also summarizes the main characteristics of the methods used for determining impact severity.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12353-1:2002, *Road vehicles — Traffic accident analysis — Part 1: Vocabulary*

ISO 6813, *Road vehicles — Collision classification — Terminology*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12353-1 and ISO 6813 and the following apply.

3.1
impact severity
changes in physical parameters of a specific vehicle due to a crash

See Figure 1.

NOTE This document deals with impact_severity. Accident severity, crash severity and collision severity are different terms related to other vehicle and environment characteristics. Impact severity (or crash severity or collision severity) is not to be confused with injury outcome, which may be a consequence of impact severity. See also ISO 12353-1:2002, Clause 4.

4 Evaluation of impact severity relating to injury outcome

4.1 Overview of different severity parameters and measures

The severity of an impact can be described according to the sequence of accident events, as shown in Figure 2. Main severity parameters are shown in ovals. The squares describe information needed to be obtained and evaluated to reach the next level of severity measures.

NOTE 1 Each of these ovals has been used to describe impact severity. The suitability of measurements for predicting injury relating to each of these ovals is discussed in 4.2.

NOTE 2 Some of the needed information in the squares would be more difficult to obtain and evaluate than other information.

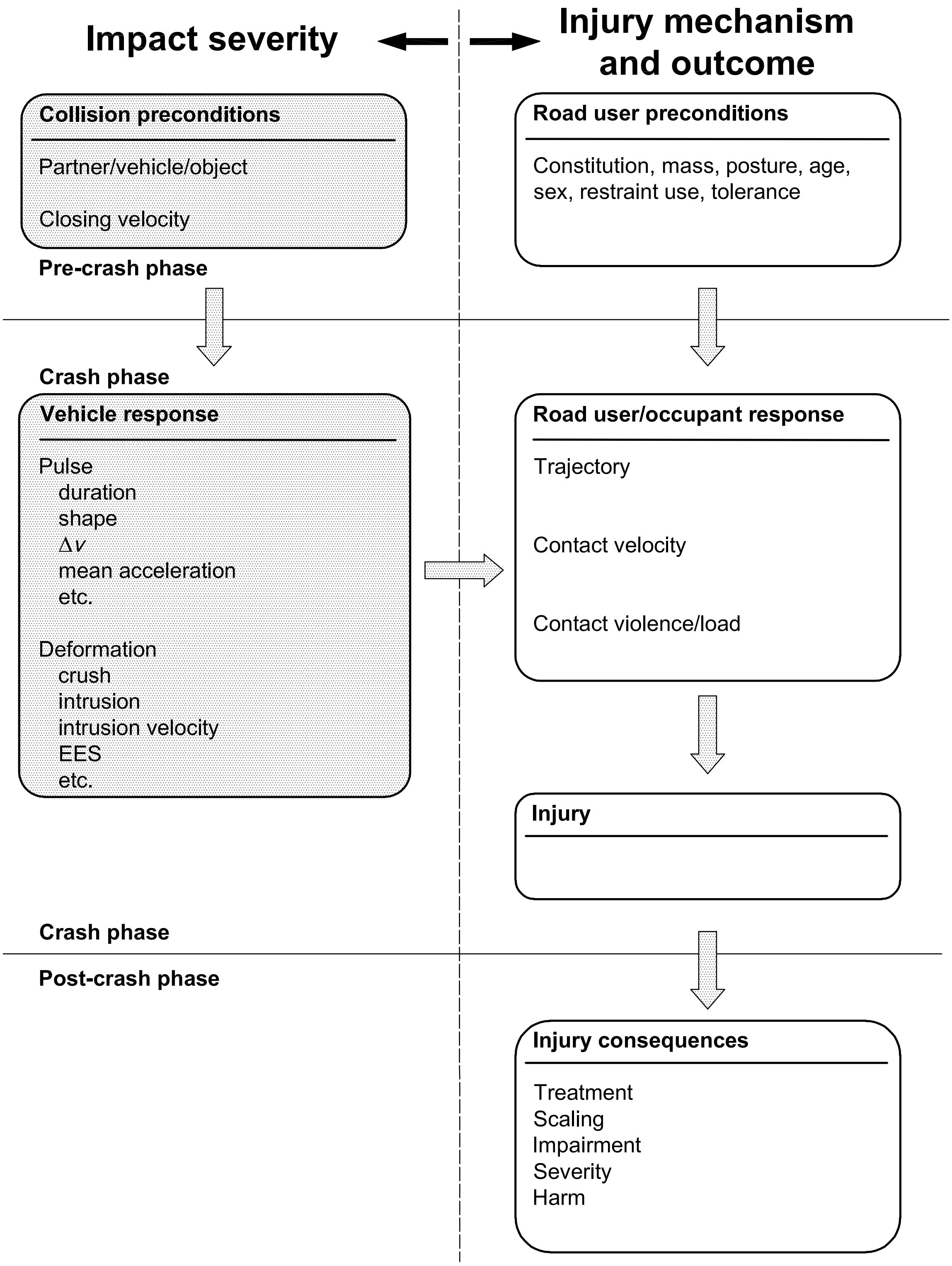


Figure 1 — Impact severity and injury mechanism/outcome (dose–response model)

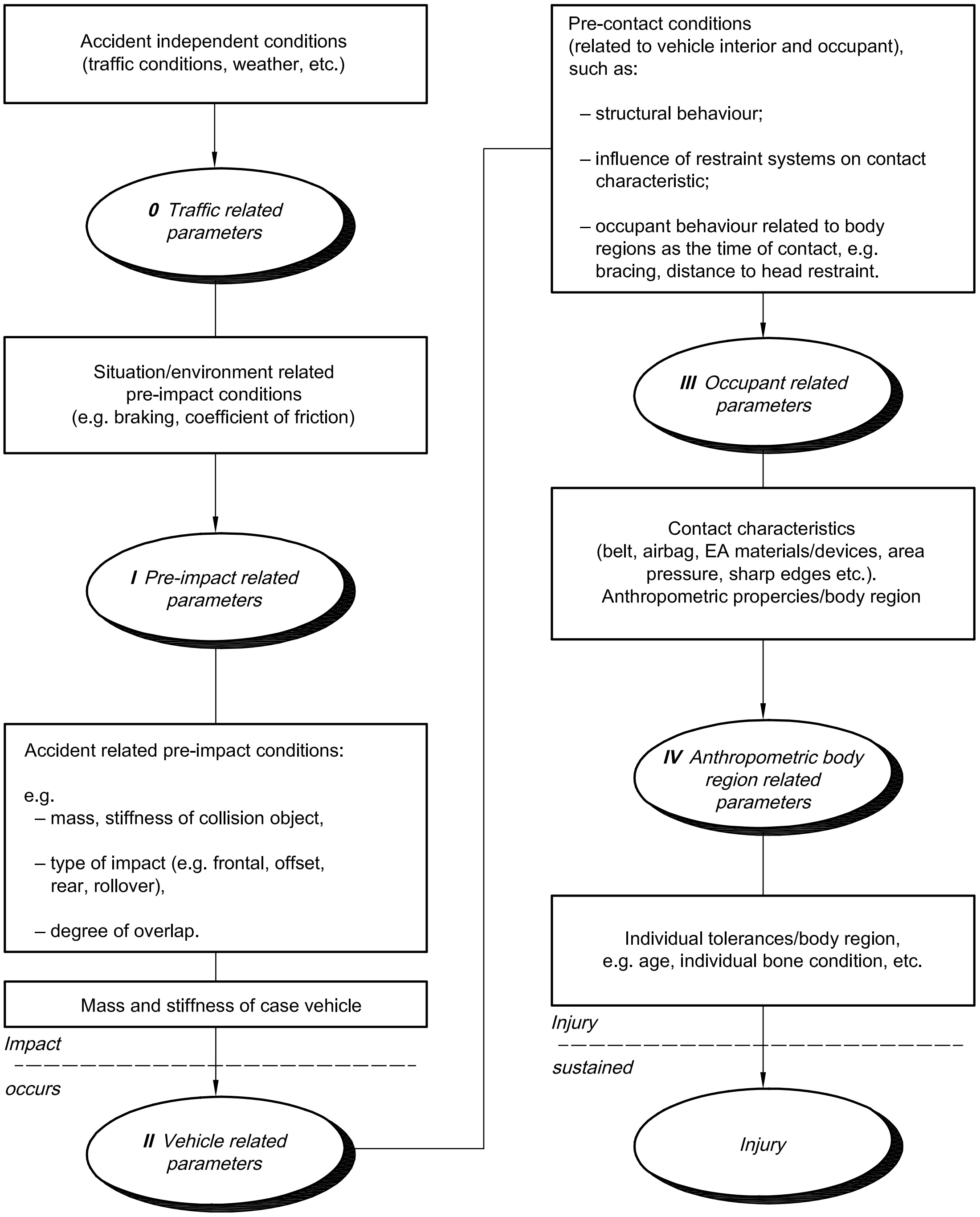


Figure 2 — Main severity parameters (ovals) and additional information to be obtained and evaluated (squares)

4.2 Suitability of parameters for description of impact severity

A number of parameters could potentially be used as measures of impact severity. These are summarized in Table 1 in categories that relate to pre-impact conditions, vehicle-related parameters, occupant-related parameters, etc.

Some of these parameters, such as the speed limit applicable to the accident site, are not considered to be suitable as measures of severity for any impact type. Others are considered to be suitable, but not necessarily for all impact types, as detailed in 4.3. For example, the change of velocity during impact, delta-v (Δv), might not be a sufficient impact severity parameter for crash types where compartment intrusion is a dominant injury factor or where mean acceleration is relatively low (intrusion velocity would be more appropriate).

NOTE Even where impact severity parameters are suitable for use and do correlate with injury, the relationship may not be causal. The extent of side door intrusion, for example, is considered to correlate with chest injuries not because it directly causes the injuries, but because it correlates with one of the causal factors (intrusion velocity).

Table 1 — Suitability of various parameters for describing impact severity

Main severity description[a]	**Severity parameters**	**Suitability as an impact severity parameter**	**+ Advantage** **– Limitation**	**Comments**
0 *Traffic related parameters*	• Speed limit • Travel speed	◊ No ◊ No	– Too remote from injury outcome	Active safety (road construction, traffic policy, risk exposure, traffic control devices)
I *Pre-impact related parameters*	• Impact velocity[b] • Closing velocity[c]	∗ Yes ∗ Yes	– Parameters from *II* are needed	Could be used for exposure data Representative crash test speeds for crash ratings and for development of vehicles (*collision* severity based)
II *Vehicle related parameters*	• Δv • EES • Damage extent, e.g. CDC[d] • Intrusion extent • Intrusion velocity • Mean acceleration • Crash pulse[e] derivatives	∗ Yes ∗ Yes ∗ Yes, partial ∗ Yes, partial ∗ Yes ∗ Yes ∗ Yes	+ Correlation with injury, but not necessarily causing injury – Vehicle dependent	To make crashworthiness comparisons possible between a case vehicle and other vehicle models, the impact severity parameter should ideally be independent of the characteristics of the case vehicle (Δv, for instance, also depends on the mass of the case vehicle).
III *Occupant related parameters*	Contact velocity and contact velocity history (between occupant body regions and vehicle interior or exterior, or objects)	◊ No, not vehicle-specific	+ Correlation with injury, but not necessarily causing injury – Vehicle and design dependent	Could be used • to improve safety design, • as a contact severity measure, • as a measure of impact severity for pedestrians.
IV *Anthropometric body region related parameters*	Load measurements in different body regions, e.g. HIC, VC, TTI	Not applicable	+ Correlation with injury severity – Vehicle and design dependent – Body region dependent	Comparison with dummy loads Biomechanical tolerances

[a] Crash sequence is defined in ISO 12353-1:2002, 5.2.

[b] See Clause A.3 and ISO 12353-1:2002, 5.9.

[c] See Clause A.4 and ISO 12353-1:2002, 5.12.

[d] See Clause A.1 and ISO 12353-1:2002, 4.3.11.

[e] See Clause A.9 and ISO 12353-1:2002, 5.22.

4.3 Suitability of measures and methods related to different impact types

Several impact severity measures can be relevant to study in the analysis of an impact. Some are more relevant than others when relating to injury outcome in a specific impact type.

Table 2 shows the impact severity measures concluded to be relevant for consideration with specific impact types.

Table 2 — Suitability of measures relating to impact types

Impact type	Impact severity measure								
	Damage extent	EES	Impact velocity	Closing velocity	Δv	Mean acceleration	Intrusion extent	Intrusion velocity	Crash pulse
Frontal impact, occupant at intrusion position	E	X			E	E	E	**XX**	E
Frontal impact, occupant not at intrusion position	E	E			X	X			**XX**
Side impact, occupant at intrusion position	E		E	X			E	**XX**	E
Side impact, occupant not at intrusion position	E	E			X	E			**XX**
Rear impact	E	E			E	X			**XX**
Unprotected road user struck by vehicle			X	**XX**					

XX = Preferred measure (if available) for impact type

X = Best if preferred measure is not available

E = Expected relationship

5 Evaluation of impact severity relating to vehicle response

In order to evaluate vehicle response, it is essential to know the closing velocity between the involved vehicles or between the vehicle and the object. It is also necessary to know all crash preconditions (impact angles, vehicle mass, contact points, etc.).

The response of the vehicle provides some input relating to the occupant response. Characteristics showing vehicle response (see also Figure 1) are

- crash pulse,
- parameters derived from the crash pulse, and
- dynamic and residual deformations.

In real-life collisions, the residual deformation is often used as the only parameter describing vehicle response; it is also frequently used as a substitute impact severity parameter when relating impact severity to occupant response in impacts with occupant compartment intrusion.

6 Conclusion

In conclusion, the following general recommendations are given.

- Appropriate methods relating to the input data available and the desired output data should be used.
- Appropriate measures for the impact type (see Table 2) should be used.
- Several relevant measures should be combined, if possible.
- When describing injury outcome for different body regions in a crash, descriptions both of the crash pulse and the performance of the occupant compartment in terms of intrusion should preferably be taken into consideration.
- Beyond the quality of the methods applied, the user should be aware of uncertainties and confidence levels of results before using them — particularly in respect of results calculated from other data rather than directly measured.

Annex A is a compilation of the methods referred to in Clauses 4 and 5. More detailed information on some of the methods can be found in the literature referenced in the Bibliography.

Annex A
(informative)

Overview of methods for determination of impact severity

A.1 Damage extent

A.1.1 General

The extent of vehicle damage is a direct vehicle response to the level of impact severity.

See ISO 6813 for the definition of deformation, and ISO 12353-1 for the definitions of crush/deformation, maximum crush, bowing/"bananaing" and end shifting.

NOTE Damage is more widely defined to include any alteration of the condition and appearance of the vehicle from that which might have existed before the incident, such as witness marks in surface dirt, paint and tyre tread transfer, scratches, gouges, torn components, buckled components and crushed panels. The alteration could have been due to contact with any other vehicle, object or terrain.

The actual damage surface is the deformed exterior structural surface of the vehicle, excluding small irregularities. ISO 12353-1 defines the crush profile as a series of measurements across the damaged area that describes the damage pattern. This series of measurements document a representative damage surface that is a three-dimensional model or facsimile of the actual damage surface. The precision of the damage model surface depends upon the number of nodal measurement points.

A damage feature point is any point, recognizable or locatable on both the damaged and an undamaged exemplar vehicle, that demonstrates some significant feature of the damage (such as a paint transfer, a point of a hood edge where buckling occurred, a puncture, holes, gouges, tears, material transfer locations, displacement vectors, terrain contacts, bowing or twisting). Hard points that have been displaced, such as axles, frames, cross members, engine/transmission, unit body strength panels and suspension members, should be included.

The displacement vector is a vector that describes the net displacement of a damage surface or damage feature point from its undamaged position to its position on the damaged vehicle.

A.1.2 Necessary input data

A.1.2.1 Damage coordinate system

The damage coordinate system is used to describe damage location and extent relative to the overall vehicle. Any convenient, three-dimensional coordinate system may be used, provided it has three independent, clearly defined coordinate directions and provided that the positions of at least three non-collinear, defined points on the non-deformed or the least-deformed part of the vehicle are measured in the same coordinate system, e.g. the centres of mounting bolts on a bumper.

A.1.2.2 Direct measurement

Positions of the damage surface in the damage coordinate system should be measured at a sufficient number of points to define the surface for the apparent purpose of the investigation. The actual damage surface is measured as a series of nodal points, excluding small irregularities. A point measured on the actual damage surface is defined as one that could be touched, for example, by an 8 cm diameter round, flat disc. Small irregularities that could not be touched by the disc are ignored or described separately as a damage feature point, such as a hole.

NOTE The position of flexible facia might not represent the actual structural damage surface, unless it is forcibly deflected into contact with the underlying structure.

Nodal measurement points should be selected and labelled to obtain sufficient data to provide a basis for determining the crush volume distribution, the model surface shape, the extent of induced damage, and major overall distortion in three-dimensional space. Nodal point locations do not need to conform to a uniform grid, but shall be recorded within the 3D damage coordinate system.

The maximum model surface deviation defines the criteria for choosing the location and number of nodal points to be used to define the representative three-dimensional model of the damage surface. The model surface deviation is chosen by the investigator as, for example, ± 5 cm or ± 10 cm, as appropriate for the situation. Sufficient nodal points are then selected on the actual damage surface to define a model surface that lies within the limits of the specified model surface deviation.

The damage model is then defined by connecting the adjacent nodal points with straight lines. The actual damage surface is represented by the series of flat triangular planes defined by the lines connecting the nodal points.

For each hard point, a description of the supporting structure, the deformation tear, bend, buckle mode of the structure, and location of the deformation or deformations should be recorded. Overall distortion such as offsetting, bowing or twisting that could influence the estimate of total energy dissipated should also be recorded.

Sufficient description shall be recorded for each point to permit another person to locate the point and verify the reported coordinate values. The description shall link the coordinate measurements to a specific point on the vehicle.

A.1.2.3 Photogrammetry

A.1.2.3.1 General

Photographs contain a wealth of information and although some of this can be discerned by unaided visual examination of the photo image, much more is available through photogrammetry. Measurements of the location of image features on a photograph can be transformed into the actual deformation shape of the vehicle by mathematical formulae. This transformation process, called photogrammetry, requires for the three-dimensional shape of vehicle crush at least two different photographic views (three views are preferred) of each area of the vehicle.

A.1.2.3.2 Photographic method

An object of known dimension, such as a large numbered scale or a traffic cone should be placed on or near the vehicle. The scale object needs to remain in the same position for all photo views that show its full image but may be moved around the vehicle for other groups of views. The vehicle is photographed providing sufficient number and variety of views to show all sides of the vehicle and the major shape of the damage surface. Each part of the vehicle should appear in at least two, preferably three, different views and the lens focal length of each photograph should be recorded, preferably use a single lens length for all the views.

A.1.3 Calculation method

Crush volume is the volume between the damaged and undamaged vehicle exterior surface.

Commercial photogrammetry programs transform sets of photographs into the actual deformation shape of the vehicle by mathematical formulae.

A.1.4 Output characteristics

This is intended to document the major geometrical topology of the exterior, damaged surface and other key damage features that may aid understanding of the dynamics of a particular collision. Measurement of the exterior damage on a vehicle is a necessary first step in quantifying the deformation caused by a collision, establishing the crush direction and in evaluating the energy dissipated by the deformation.

The significance of the data gathered using photogrammetry includes the following.

Crush volume is the volume between the undamaged vehicle exterior surface and the exterior surface after it has been crushed by collision forces and can be empirically related to the energy dissipated during permanent deformation of the structure. Energy dissipated during a collision is directly related to the magnitude of the EES (Energy Equivalent Speed) if the vehicle mass is taken into account, and to the change in angular velocity. The distribution of crush volume across the vehicle structure is used to estimate the location of the collision impulse point.

The boundary of each direct contact zone suggests the general position and orientation of the vehicle relative to the contacting object at maximum engagement.

Displacement vectors pass through a specified point on the damaged surface and originate at that point's location on the undamaged vehicle. The appropriately weighted average of the displacement vectors approximates the collision impulse direction.

The damage surface shape suggests the initial collision orientation and relative positions of the colliding objects at maximum engagement.

Induced damage could involve a significant portion of the energy dissipated during the collision.

Different deformation modes of key structural elements (bending, wrinkling and tearing) do not necessarily absorb the same energy for the same displacement and could influence the estimate of the impulse point location and the estimate of the energy absorbed by the structure.

A.1.5 Advantages, limitations, accuracy, sensitivity, applicability

Applicability to injury outcome of this method is summarized in Table 2. The prime advantage of residual damage extent as a measure of impact severity is that it remains observable and measurable after the vehicle impact is over. The velocity, acceleration and energy dissipation of a vehicle during impact are transient and unobservable after the event. Measures of impact severity related to velocity, acceleration or energy are therefore more difficult to determine (assuming no recording devices are fitted to the crashed vehicles). For the same reason, damage extent may be measured to whatever high degree of accuracy is desired.

Vehicle damage, however, is imperfectly correlated to the impact severity parameters that are more directly linked to the risk of occupant injury, such as passenger compartment acceleration, intrusion velocity, Δv and EES. A high level of external crush to a vehicle with crumple zones can indicate a low level of acceleration during impact, while the opposite can be true of a low level of external crush in a very stiff vehicle. Nonetheless, vehicle damage is used to support the estimation of other severity measures, such as Δv, EES and other dynamic vehicle response parameters.

A.2 EES

A.2.1 General

See ISO 12353-1:2002, 5.15, for a definition of EES.

A.2.2 Necessary input data

Because the EES is in principle a deformation energy, which is only given as a speed term, the deformation characteristic of the studied vehicle shall be known.

A.2.3 Calculation method

According to ISO 12353-1, the deformation energy equals

$$\tfrac{1}{2} \times m \times \left(\text{EES}\right)^2$$

where m is the effective mass of the vehicle at impact, expressed in kilograms.

The following main methods are available for determining of EES.

a) Estimation of the EES by investigating the vehicle involved in the accident and comparing the deformation pattern with that found in similar crash tests: EES data brochures are published to this purpose.

b) A more sophisticated method is to use energy grids to calculate the EES on the basis of the deformation measurements (see Bibliography).

c) Another method is to use approximation equations that are based on deformation depth and width in correlation with the energy absorbed for frontal impacts with different overlap. See [1].

d) Damage-based algorithms can also be used to estimate EES. These use either model specific or generalized input data (see Bibliography).

A.2.4 Output characteristics

The result is a vehicle-related physical parameter independent of the motion of the vehicle during the accident. It is given in metres per second or kilometres per hour, but describes the absorbed deformation energy only.

A.2.5 Advantages, limitations, accuracy, sensitivity, applicability

EES is a very suitable, even preferred measure, when mass and damage information is known but trajectory information is incomplete. It shows a good correlation with the injury outcome of the occupants, especially in frontal impacts, but only due to the fact that EES correlates well with intrusion velocity that might cause severe injuries. It does not depend on the information about the accident scene and collision partners, i.e. it can be arrived at using information about the damaged vehicle only and needs no accident reconstruction.

The EES value cannot be calculated precisely. There is not always sufficient information about the energy absorption characteristic: not for every vehicle and especially not for every damage zone and impact configuration. Equally, similar crash tests may not be available for an equivalent vehicle, thus limiting the accuracy of photographic methods.

The EES is applicable for all kind of damage, but due to the above mentioned restrictions it should only be used if comparable crash data are available.

The application of averaged stiffness properties can result in more or less significant inaccuracies. As a consequence, data related to a specified vehicle model and impact configuration should be used.

Theoretical application examples comparing Δv and EES in various impact circumstances are given in Annex B.

A.3 Impact velocity

A.3.1 General

See ISO 12353-1:2002, 5.9, for a definition of impact velocity.

A.3.2 Necessary input data

Observations and measurements from the scene of the accident are normally required to obtain an estimate of impact velocity. These may include, for example, the location of impact, the post-impact (rest) positions of the colliding vehicles, tyre marks before, during or after impact, frictional properties of the road surface, and the direction of travel of the colliding vehicles prior to impact. Crush profiles and estimates of energy dissipation may also be incorporated into the analysis.

A.3.3 Calculation method

The impact velocity can be calculated with the aid of physical theorems such as the conservation of momentum, the conservation of energy and the conservation of angular momentum in a backward reconstruction, or based on a given travel speed and other parameters with the aid of, for example, skid marks up to the initial point of impact in a forward reconstruction. Because the impact velocity is a vector, a local coordinate system shall be used for the calculations.

A.3.4 Output characteristics

The impact velocity is expressed in metres per second or kilometres per hour.

A.3.5 Applicability, advantages, limitations, accuracy, sensitivity

The applicability is explained in Table 2. Impact velocity can relate to injury outcome in collisions with fixed objects. In two-car collisions, the closing velocity or impact speed of both vehicles shall be known in order to relate to injury outcome.

Impact velocity can correlate with change of velocity in collisions with fixed objects, except from the elastic effects of the vehicle structure, which usually generate a higher change of velocity than the impact velocity.

A.4 Closing velocity

A.4.1 General

See ISO 12353-1:2002, 5.12, for a definition of closing velocity.

A.4.2 Necessary input data

The same observations and measurements that are used to estimate impact velocity may be used for closing velocity, since closing velocity is simply the vector difference between the impact velocities of the colliding vehicles. For an impact with a stationary object, the closing velocity of the vehicle is simply its impact velocity.

A.4.3 Calculation methods

The calculation methods are as for impact velocity.

A.4.4 Output characteristics

Closing velocity is expressed in metres per second or kilometres per hour.

A.4.5 Applicability, advantages, limitations, accuracy, sensitivity

The applicability is explained in Table 2. The closing velocity is the only parameter possible to use as impact severity when relating impact severity to vehicle response. It may also be useful when relating impact severity to injury outcome in impacts with glance-off and severe intrusion.

A.5 Δv (delta-v)

A.5.1 General

See ISO 12353-1:2002, 5.18, for a definition of the change of velocity Δv. It is, in effect, the difference between the velocity of a vehicle immediately before and after impact.

According to ISO 12353-1, Δv is calculated as:

$$\Delta\vec{v} = \vec{v}_1 - \vec{v}_0$$

where

$\vec{v}_0$ is the velocity vector of CG (centre of gravity) of a vehicle before impact;

$\vec{v}_1$ is the velocity vector of CG of a vehicle after impact.

A.5.2 Necessary input data

The same observations and measurements that enable impact velocity or closing velocity to be calculated are applicable to Δv. As indicated in A.3.2, these include accident scene data such as the impact location, rest positions, tyre marks, frictional properties and pre-impact travel directions. In addition, under certain circumscribed accident conditions, Δv may be deduced from the direction of impact force and the total energy dissipated by the colliding objects. Using this technique, the direction of impact force is normally judged directly at inspection of the crashed vehicle or vehicles and energy dissipation is inferred from measured crush profiles and reference tables of vehicle stiffness values.

A.5.3 Calculation method

Different methods which calculate either forward or backwards can be used. The separation velocity can be calculated, e.g. based on an analysis of the running out trajectory using realistic assumptions for the movement of the vehicle during that phase. The impact velocity can be calculated with the aid of physical theorems such as the conservation of momentum, the conservation of energy and the conservation of angular momentum in a backward reconstruction, or based on a given travel speed, and other parameters, with the aid of tyre marks, for example, up to the initial point of impact in a forward reconstruction. Once the impact velocity and separation velocity for a vehicle have been obtained, Δv follows directly as the vector difference between these parameters. Because the impact velocity and the separation velocity are vectors, the directions of the velocities shall be calculated in a local coordinate system. If Δv is calculated in a backward reconstruction with the aid of deformation energy, it is necessary to know the entire deformation energy and the running out velocities and directions as well as one running in trajectory, i.e. both an accident sketch (final positions of the vehicles in relation to the point of maximum impact) and knowledge about the accident partners involved are absolutely necessary.

NOTE See also A.9 concerning calculation of velocity change using a crash pulse recorder.

A.5.4 Output characteristics

The result is a vehicle-related physical parameter independent of the energy absorption of the vehicle itself. It is given in metres per second or kilometres per hour and describes the change of the motion of a vehicle in its local coordinate system.

A.5.5 Advantages, limitations, accuracy, sensitivity, applicability

The change of velocity is applicable for frontal, rear and side impacts but makes no sense for rollovers or pitchovers. For this to be calculated, an accident shall be well documented. It shows on average quite good correlation with the injury outcome of the occupants in certain impact types (see Table 2). Because Δv does not depend on the deformation characteristics of the vehicle, the consequence for the occupants can be significantly different at equal changes of velocity depending on the shape of the deceleration pulse.

Delta-v is generally more closely linked to mean vehicle acceleration during impact than measures of energy dissipation (such as EES) or damage extent, and is useful for this reason. However, the calculation of Δv, no matter how generally, involves a multiplicity of factors, all of which may influence the accuracy of the result to a greater or lesser degree. Except where crash pulse recorders are fitted, or an accident happens to be filmed, it is generally impossible to check the accuracy of a calculated Δv, and so the reliability of the various techniques may be subject to question. This applies to all the methods currently in use that are based on evidence from the scene of the accident and from examination of the crashed vehicles. In this context, the introduction of crash pulse recorders is highly desirable.

For certain purposes (e.g. crashworthiness ratings or the evaluation of a modified vehicle design) the dependence on vehicle properties is a complication. Delta-v, for instance, is dependent on the mass ratio of the case vehicle and the counterpart vehicle. If a change of vehicle mass is part of a modified design, the modified vehicle will receive a Δv other than the baseline vehicle when encountering exactly the same counterpart vehicle at the same closing velocity, i.e. all ”external” factors remaining constant. Consequently, the modified vehicle will face a different Δv-distribution in real-life accidents than before the mass modification (all other factors, including closing velocities remaining constant). This makes crashworthiness comparisons between vehicles complicated, since the impact severity parameter used for the comparison should ideally be independent of the case vehicle characteristics.

NOTE The accuracy of Δv depends on the accuracy of the whole accident documentation and reconstruction, as discussed above. In particular, the effects of glance-off have to be carefully considered in order to achieve a reliable Δv. If glance-off effects are not taken into account when they occur, there is a risk of overestimation of the Δv. See also the application examples given in Annex B.

A.6 Mean acceleration

A.6.1 General

See ISO 12353-1:2002, 5.22.1, for a definition of mean acceleration

A.6.2 Necessary input data

For the calculation, the impact velocity and the separation velocity shall be known, as well as the maximum dynamic crush (Δs) of the case vehicle and the other vehicle or object struck measured in relation to the direction of principal force.

A.6.3 Calculation method

According to ISO 12353-1, the mean acceleration can be calculated as:

$$\bar{a} = \frac{v_0^{\,2} - v_1^{\,2}}{2\Delta s}$$

NOTE Given the availability of crash pulse recorder results, the mean acceleration can be calculated with respect to Δt.

A.6.4 Output characteristics

The mean acceleration is expressed in metres per second squared or, alternatively, in “g”s.

A.6.5 Advantages, limitations, accuracy, sensitivity, applicability

The result is not very accurate due to the lack of information about the dynamic crush, but it is sufficient to use the residual crush disregarding any restitution. Use of a crash pulse recorder can provide improved accuracy. The result is not very sensitive towards this effect, because the mean acceleration shows a wide variety of values in vehicle-to-vehicle collisions and is used as an additional parameter in combination with EES or Δv to describe the impact severity. The method is applicable to vehicle-to-vehicle impacts and impacts of vehicles against rigid and deformable objects.

A.7 Intrusion extent

A.7.1 General

Intrusion extent is the residual occupant compartment intrusion after an impact for a specific part of the vehicle related to the undeformed vehicle. Apart from the measurable residual occupant compartment intrusion, there is an additional dynamic deformation recovering after the crash phase.

A.7.2 Necessary input data

These consist of measurements of the residual occupant compartment intrusion of the deformed area or point, and measurements of the corresponding area or point from an undeformed vehicle.

A.7.3 Calculation method

The measurements of the residual occupant compartment intrusion shall be related to those in the undeformed vehicle.

A.7.4 Output data

The intrusion extent can be measured in three directions, or as a resultant deformation vector in metres. It is also possible to express it as a deformed volume (in cubic metres), or as a percentage reduction in volume or distance.

A.7.5 Applicability advantages, limitations, accuracy, sensitivity

Applicability to injury outcome is summarized in Table 2. Although in real-life conditions the intrusion extent may not have a causal relationship to injury outcome, correlations are found relating intrusion extent to injury outcome.

Intrusion extent can sometimes be difficult to measure as there may be difficulties in defining previously measured reference points in the deformed vehicle.

Intrusion extent is related to EES, not to Δv.

A.8 Intrusion velocity

A.8.1 General

See ISO 12353-1:2002, 5.10, for a definition of intrusion velocity.

A.8.2 Necessary input data

The intrusion and the time frame in which the intrusion occurs or the acceleration versus time characteristic of the intruding parts shall be known.

A.8.3 Calculation method

The mean intrusion velocity can be calculated as the quotient of intrusion and duration of intrusion. The exact intrusion velocity versus time can be evaluated by integration of the acceleration of the intruding part or by derivation of the intrusion versus time history on the basis of a high-speed film analysis.

A.8.4 Output characteristics

The result is given in metres per second or kilometres per hour.

A.8.5 Applicability, advantages, limitations, accuracy, sensitivity

Applicability to injury outcome of this method is summarized in Table 2.

In a crash test, the integration of the acceleration of an intruding sheet metal of the body structure is not very accurate because of vibration and the motion of accelerometers causing a movement of the measurement axis. Recording by high-speed film is sometimes difficult because of camera positioning, e.g. in the footwell area.

The calculation of the intrusion velocity of intruding parts, e.g. a steering wheel, can be done accurately on the basis of a film analysis. In real-world accidents, the mean intrusion velocity can only be roughly estimated.

A.9 Crash pulse

A.9.1 General

See ISO 12353-1:2002, 5.22, for a definition of crash pulse.

A crash pulse recorder can be used for the measurements. If the crash pulse is recorded in accidents, it is possible to accurately calculate different pulse characteristics describing impact severity. It is then possible to do analyses regarding the link between these parameters and injury outcome.

The following parameters are examples of those which can be calculated:

- Δv;
- mean acceleration;
- duration of impact phase;
- peak acceleration;
- time to peak acceleration.

A.9.2 Necessary input data

The acceleration time history of the vehicle shall be recorded, preferably at the CG.

A.9.3 Calculation methods

The acceleration time history can be evaluated in accordance with ISO 6487 and SAE J211 at CFC 60 Hz. The crash pulse recorder may record linear and rotational acceleration time history in one, two or three directions.

A.9.4 Output characteristics

Acceleration – time history during the impact phase, and derived parameters listed above.

A.9.5 Applicability, advantages, limitations, accuracy, sensitivity

The impact severity in terms of a crash pulse can be recorded to obtain an in-depth knowledge of how the crash pulse characteristics relate to injury outcome.

Advantages:

- detailed description of the impact phase;
- link between pulse characteristics and injury outcome;
- computerized analysis in crash simulation modelling.

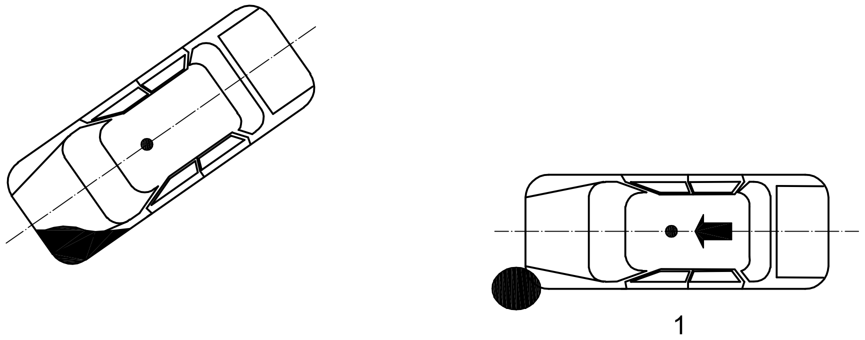
Limitations:

- if only one direction is recorded, angular considerations shall be taken into account;
- if the crash pulse recorder is not positioned at the centre of gravity in the vehicle, considerations could be taken for that as well.

Annex B
(informative)

Application examples with EES and delta-v

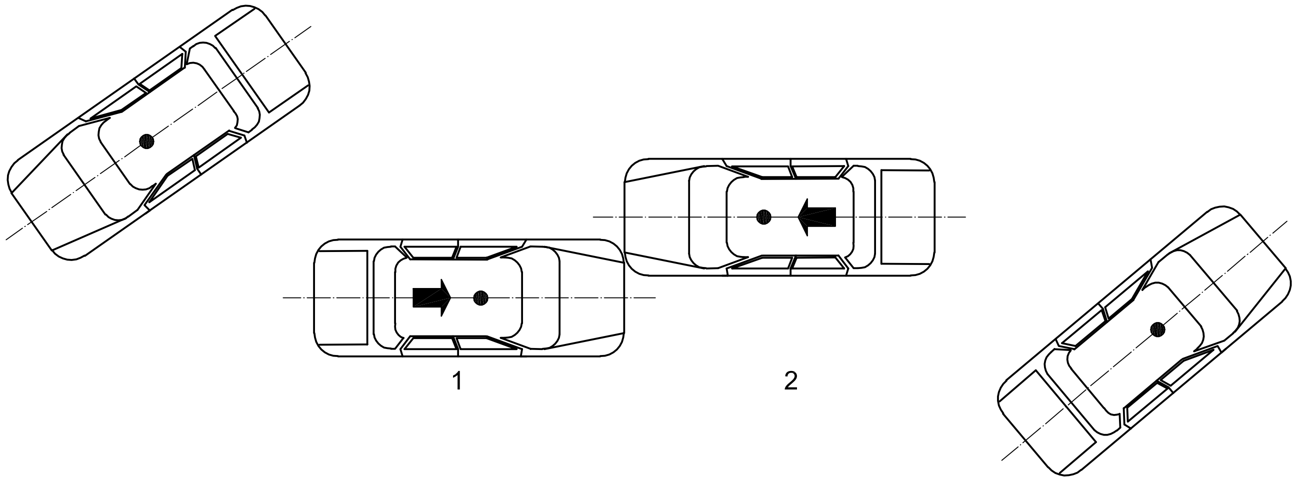
See Figures B.1 to B.6.



$v_0 1$: 100,00 km/h
EES1: 50,00 km/h
$v_1 1$: 86,60 km/h
$\Delta v1$: 13,40 km/h

v_0	velocity before impact
v_1	running out velocity

Figure B.1 — Case 1 — Extreme case of theoretical glance-off, when assumed that EES is known

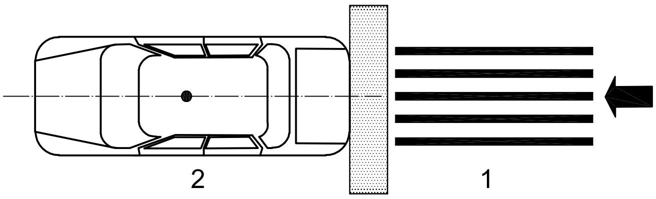


$m1 = m2$
$v_0 1$: 70,00 km/h
$v_0 2$: −50,00 km/h
EES1: 50,00 km/h
EES2: 50,00 km/h

$v_1 1$: 40,00 km/h
$v_1 2$: −20,00 km/h
$\Delta v1$: 30,00 km/h
$\Delta v2$: 30,00 km/h

v_0	velocity before impact
v_1	running out velocity
m	vehicle mass

Figure B.2 — Case 2 — Glance-off case for two vehicles with known EES values



$m1 = m2$

$v_0 1$: 50,00 km/h

$v_0 2$: 0,00 km/h

EES1: 0,00 km/h

EES2: 35,00 km/h

$v_1 1$: 25,00 km/h

$v_1 2$: 25,00 km/h

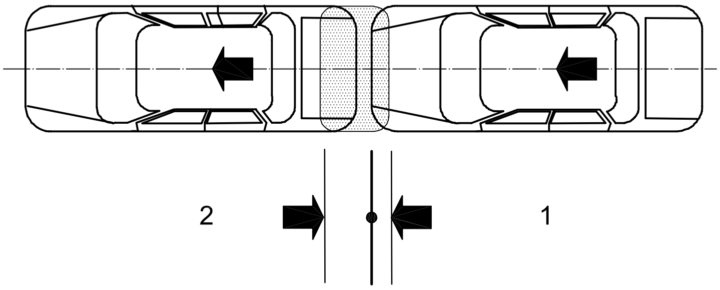
$\Delta v1$: 25,00 km/h

$\Delta v2$: 25,00 km/h

v_0	velocity before impact
v_1	running out velocity
m	vehicle mass

NOTE The EES is calculated by means of a theoretically simplified derivation from the momentum and energy theorem. The EES value of 35 km/h is rounded. The exact value is calculated by multiplication of the impact speed and $1/2 \cdot \sqrt{2}$.

Figure B.3 — Case 3 — Rear impact with movable barrier



$m1 = m2$

$v_0 1$: 80,00 km/h

$v_0 2$: 20,00 km/h

EES1: 25,00 km/h

EES2: 34,00 km/h

$v_1 1$: 50,00 km/h

$v_1 2$: 50,00 km/h

$\Delta v1$: 30,00 km/h

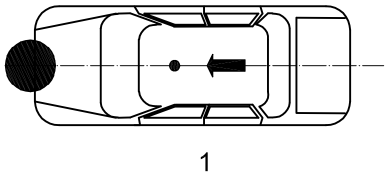
$\Delta v2$: 30,00 km/h

SDEF1: 0,28 m

SDEF2: 0,54 m

v_0	velocity before impact
v_1	running out velocity
m	vehicle mass

Figure B.4 — Case 4 — Example for case of a vehicle/vehicle impact, where different stiffness results accordingly in different deformation



$v_0$1: 50,00 km/h

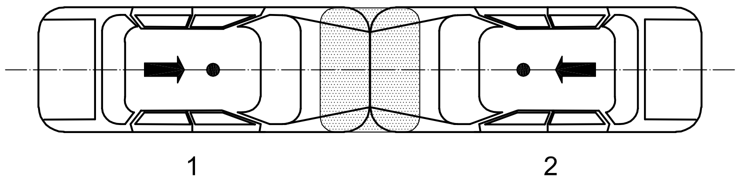
EES1: 50,00 km/h

$v_1$1: 0,00 km/h

Δv1: 50,00 km/h

v_0	velocity before impact
v_1	running out velocity

Figure B.5 — Case 5 — Central impact against rigid obstacle; Δv equals EES



$m1 = m2$

$v_0$1: 80,00 km/h

$v_0$2: −20,00 km/h

EES1: 50,00 km/h

EES2: 50,00 km/h

$v_1$1: 30,00 km/h

$v_1$2: 30,00 km/h

Δv1: 50,00 km/h

Δv2: 50,00 km/h

v_0	velocity before impact
v_1	running out velocity
m	vehicle mass

Figure B.6 — Case 6 — Impact of two similar vehicles at theoretically ideal impact configuration; Δv equals EES

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