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BSI Standards Publication

Road vehicles — Traffic accident analysis

Part 3: Guidelines for the interpretation of recorded crash pulse data to determine impact severity

National foreword

This Published Document is the UK implementation of ISO/TR 12353-3:2013.

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TECHNICAL REPORT

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Road vehicles — Traffic accident analysis —

Part 3: Guidelines for the interpretation of recorded crash pulse data to determine impact severity

Véhicules routiers — Analyse des accidents de la circulation —

Partie 3: Lignes directrices pour interpréter l'enregistrement de gravité des chocs

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Foreword

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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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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/TR 12353-3 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*

— *Part 3: Guidelines for the interpretation of recorded crash pulse data to determine impact severity* [Technical Report]

Introduction

With the completion of ISO 12353-2, an important extension is guidelines for the use and application of the in-vehicle recorded crash pulse data. The aim of ISO/TR 12353-3 is to provide definitions and recommended measurements of impact severity data recording to be used in evaluation and analyses. This will facilitate a comparison of different accident databases, and urge on the work of accident analyses based on impact severity data recording. The higher quality of impact severity determination will improve the accuracy of analyses and development work for the industry, governments and others.

As more advanced active and passive safety technology is introduced in motor vehicles, it is important to continuously evaluate the technology to determine its efficiency. Furthermore, it is essential to explore occupant injury risk and severity for impact severity parameters best correlated to injury risk. Studies of real-life crashes are the most important way to gain such knowledge.

Different types of accident data recorders have been developed and used for the purposes of improving data quality. Car manufacturers also use data from sensors and recording devices in the development process of new safety technology and to verify the effectiveness of existing technology.

Specifically for impact severity parameters, there is a need for definitions of their measurements, recording, and process of calculation. This Technical Report concentrates on the data that can be obtained from crash pulse data recorders for determination of impact severity.

The recorded data may be either acceleration-time data or change of velocity (Δv) time data. This Technical Report includes methods applicable to the interpretation of recorded Δv data from event data recorders (EDR) fulfilling the requirements of United States Code of Federal Regulations 49 CFR Part 563.[1]

This Technical Report focuses on the crash pulse characteristics in Figure 1, the Dose – Response model (also referred to in ISO 12353-2), slightly modified for the purposes of this Technical Report.

As shown in Figure 1 several parameters are influencing the risk of an injury. This Technical Report focuses on the influence of crash pulse characteristics on injury risk.

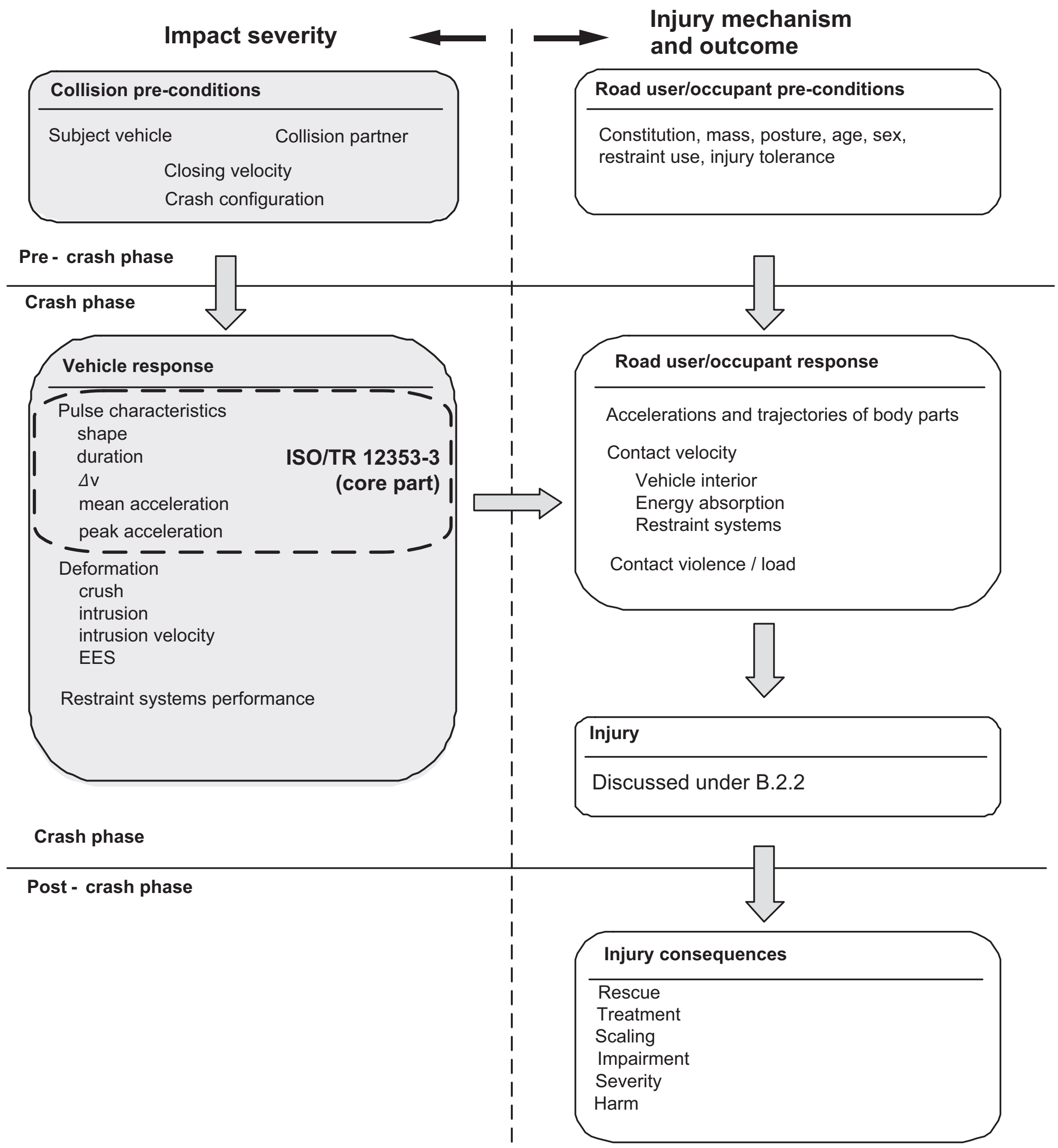


Figure 1 — Impact severity and injury mechanism/outcome (Dose – Response model)

With crash pulse recording techniques, and using a recorder in the undeformed part of the vehicle chassis, it is possible to quantify physical crash pulse parameters during a vehicle crash. This is what the vehicle restraint systems and the vehicle interior will have to handle in order to minimize the loading on the vehicle occupants.

This Technical Report discusses the recorded physical parameters that are relevant to take into account for certain impacts, and also discusses the possible misuse and traps when using crash pulse data.

Road vehicles — Traffic accident analysis —

Part 3: Guidelines for the interpretation of recorded crash pulse data to determine impact severity

1 Scope

This Technical Report describes the determination of impact severity in road vehicle accidents as defined in ISO 12353-2, based on recorded acceleration and velocity data and derived parameters from vehicle crash pulse recorders or event data recorders, including data from self-contained devices or vehicle integrated functionalities. Methods applicable to the interpretation of recorded Δv data from event data recorders fulfilling the requirements of United States Code of Federal Regulations 49 CFR Part 563 are also included.

This Technical Report includes definitions and interpretation of recorded data related to impact severity determination. Some information on application of the data are also provided.

The purpose of this Technical Report is to interpret available recorded crash pulse data. The methods in this Technical Report are applicable to interpretation of crash pulses in both longitudinal and lateral directions. However, based on available data, most examples are given for the longitudinal direction.

This Technical Report does not address aspects such as the pre-crash phase, data element specifications, and data recording and retrieval technology.

2 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, *Road vehicles — Traffic accident analysis — Part 1: Vocabulary*

ISO 12353-2, *Road vehicles — Traffic accident analysis — Part 2: Guidelines for the use of impact severity measures*

ISO 4130, *Road vehicles — Three-dimensional reference system and fiducial marks — Definitions*

ISO 6487, *Road vehicles — Measurement techniques in impact tests — Instrumentation*

SAE J211-1, *Instrumentation for Impact Test — Part 1: Electronic Instrumentation*

SAE J1698-1, *Vehicle Event Data Interface — Output Data Definition*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4130, ISO 12353-1, ISO 12353-2, SAE J1698-1, and the following apply.

3.1
crash pulse recorder
device or unit capable of recording acceleration or Δ*v*-time history data during the impact phase

Note 1 to entry: Crash pulse recorder is used as a generic term in this Technical Report to differentiate from Event Data Recorders as defined in 49 CFR Part 563.

3.2
Event Data Recorder
EDR
device or function in a vehicle that records the vehicle's dynamic time-series data during the time period just prior to a crash event (e.g. vehicle speed vs. time) or during a crash event (e.g. Δ*v* vs. time), intended for retrieval after the crash event

Note 1 to entry: The definition is in accordance with 49 CFR Part 563.

Note 2 to entry: Data elements other than time series data are often recorded.

3.3
linear acceleration
acceleration in any direction during an impact event

3.3.1
longitudinal acceleration
acceleration in the vehicle X-axis direction during an impact event

3.3.2
lateral acceleration
acceleration in the vehicle Y-axis direction during an impact event

3.3.3
vertical acceleration
acceleration in the vehicle Z-axis direction during an impact event

3.4
rotational acceleration
acceleration about one of the vehicle axes

3.4.1
yaw acceleration
acceleration around the vehicle Z-axis

3.4.2
pitch acceleration
acceleration around the vehicle Y-axis

3.4.3
roll acceleration
acceleration around the vehicle X-axis

3.5
Δ*v* – time history
cumulative history of developing change of velocity resulting in Δ*v*

3.6
jerk
third derivative with respect to time of the position of an object; equivalently the rate of change of the acceleration of an object

Note 1 to entry: Considered a measure of harshness of vehicle motion.

4 Basic principles of crash pulse and derived measures

The crash pulse time history provides the possibility of a superior determination of impact severity compared to e.g. deformation-based Δv and EES (Energy Equivalent Speed), in several impact types.

The whole crash pulse is not possible to use as a single parameter for impact severity, but certain characteristics of the crash pulse can be useful in interpreting the injury outcome in certain impact types.

Some characteristics can be directly obtained or calculated from the crash pulse, e.g.:

— (maximum cumulative) Δv;

— peak acceleration;

— time to peak acceleration;

— mean acceleration;

— and to some extent, the total duration.

For the calculation of some of these parameters the start and end time of the crash pulse need to be defined, as the pulse duration needs to be defined. This is discussed in detail in 5.2.3.

Distance, velocity, acceleration and jerk time histories, if not directly recorded, can be derived by differentiation or integration.

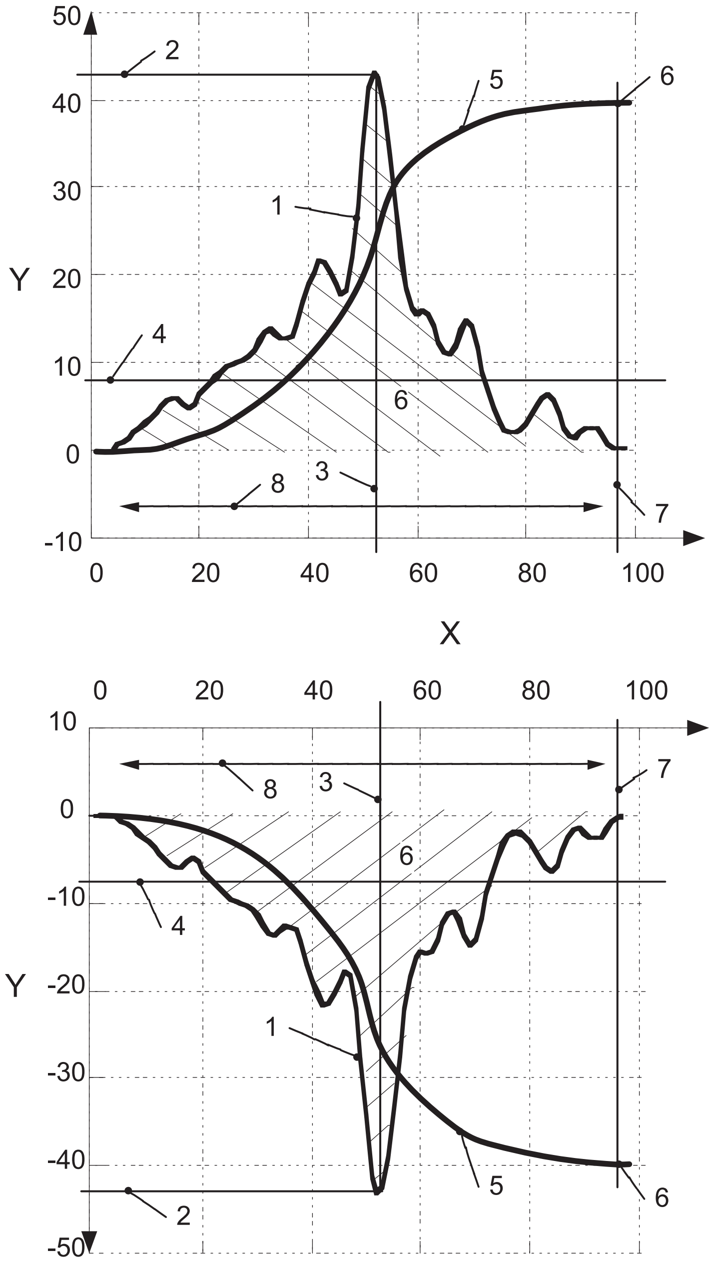
Δv can be obtained as the final value of the Δv-time history curve using the defined pulse duration, also known as the area under the acceleration curve. Details of how to calculate these parameters are further described and discussed in Clause 5.

The Δv-time history, the cumulative history of developing change of velocity, can be derived from the acceleration-time history as the cumulative area under the crash pulse within a specified time period:

$$\Delta v(t) = \int a(t)dt$$

where a is the acceleration (crash pulse).

Figure 2 illustrates a generic crash pulse with main characteristics and some derived parameters. Figure 3 illustrates the same generic crash pulse with corresponding jerk, distance, and velocity curves.



Key

1	acceleration-time history	6	Δ*v* (maximum cumulative Δ*v*, also given by the area under the crash pulse)
2	peak acceleration	7	time to maximum, Δ*v*
3	time to peak acceleration	8	pulse duration, Δ*t*
4	mean acceleration	X	time [ms]
5	Δ*v*-time history	Y	acceleration [g], change of velocity [km/h]

NOTE The diagram is shown with both positive and negative y-axis, both are commonly used in the literature. This Technical Report does not have a preference for either type of representation, and both types are shown in examples.

Figure 2 — Crash pulse with derived parameters (shown with positive and negative y-axis)

In Figure 3, four parameters are shown, all derived from the recorded acceleration-time history:

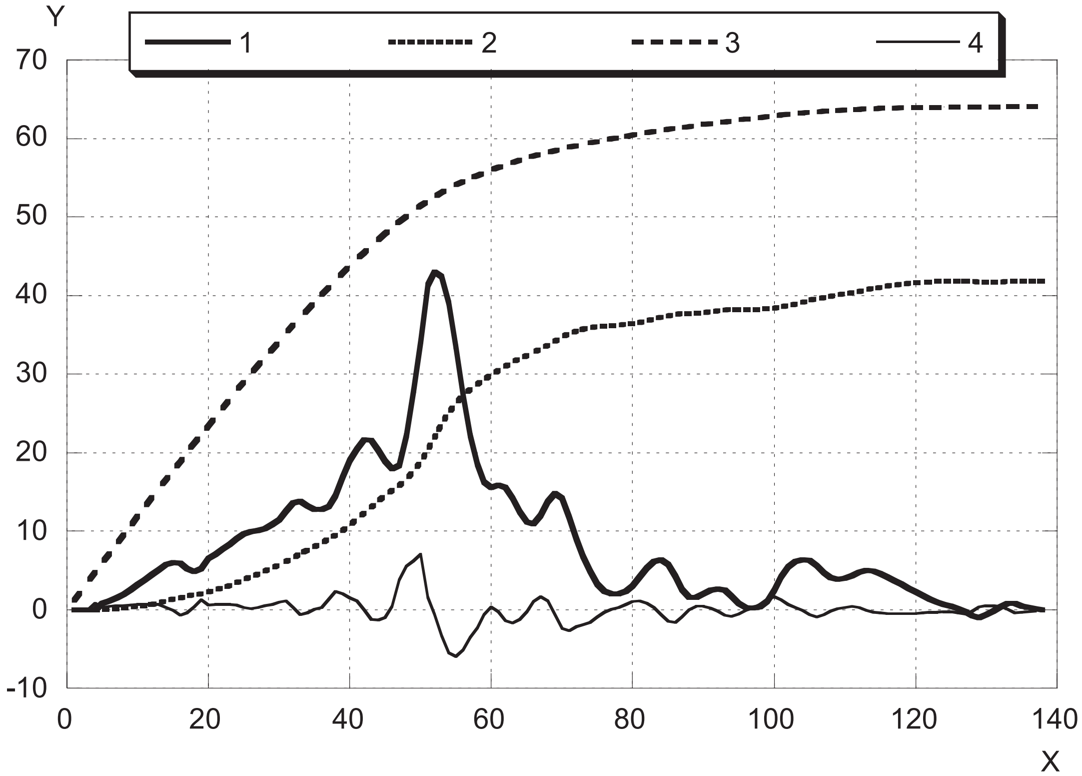
— Acceleration-time history;

— Δv-time history;

— Distance-time history of the centre of gravity (or the crash pulse recorder);

— Jerk-time history.

From these calculated parameters, peak jerk, Δv and Δs can be derived.



Key

1 crash pulse (acceleration-time history) [g]
2 Δv-time history [km/h]
3 distance-time history of the CG (or the crash pulse recorder) [cm]
4 jerk time history [m/s^3] (magnified 10 times)
X time [ms]
Y acceleration [g], change of velocity [km/h], distance [cm], jerk [m/s^3/10]

Figure 3 — Crash pulse with corresponding jerk, distance, and velocity curves

5 Guidelines for basic interpretation of crash pulse recorder data

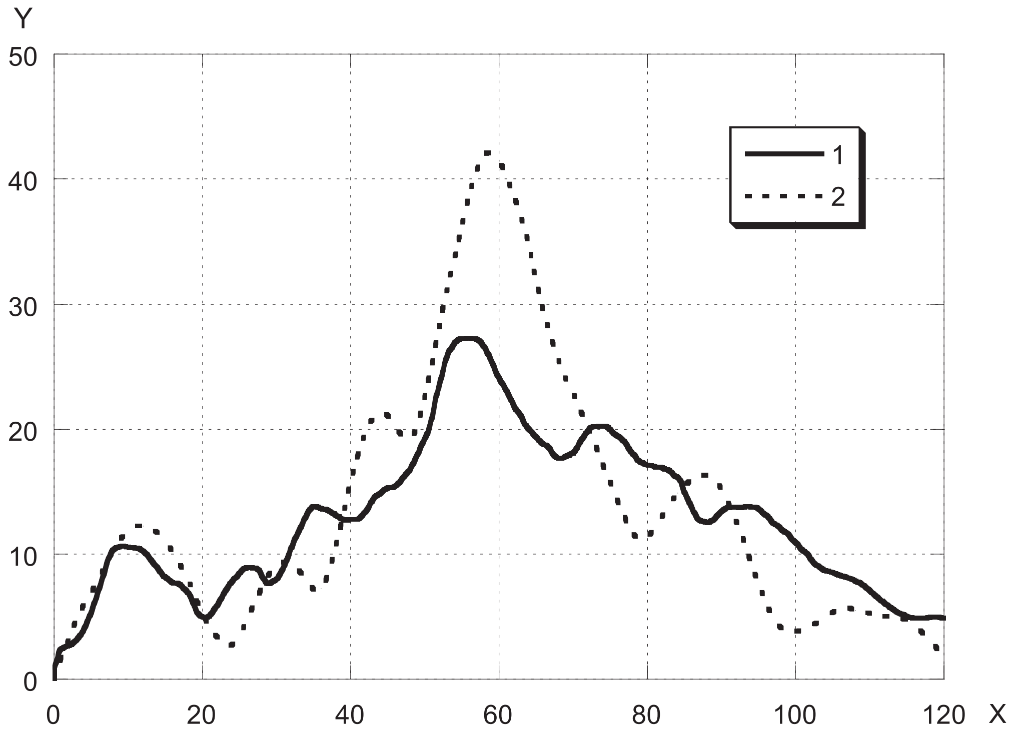
5.1 General

The procedure of exactly how to describe impact severity is still an open issue although ISO 12353-2 has defined parameters relevant to certain crash configurations.

Most of the world-wide acting in-depth accident investigation teams use the change of velocity, Δ*v*, or the Energy Equivalent Speed (EES), as a parameter for impact severity when presenting results of the injury outcome versus impact severity.

There is a wide scatter of the results when the correlation of Δ*v* or EES and injury outcome is analysed. One of the reasons for the scatter of injury outcome is the injury severity scaling system itself. Other reasons are the variability in human-related parameters such as age, gender or body weight.

Another reason is that even at identical parameter values for impact severity like Δ*v*, the acceleration crash pulse can be significantly different. The latter can be demonstrated by comparison of, e.g. the dummy chest loading for different crash tests with identical Δ*v* and EES values but significantly differing acceleration crash pulses. For a meaningful comparison, all other important parameters such as vehicle crash performance and restraint systems have to be identical. These conditions are effectively fulfilled for a series of four frontal impacts shown in D.1. Figure 4 illustrates an example from those.



Key

1 car-to-car impact with 57 % overlap and a closing velocity of 110 km/h

2 impact against a rigid barrier with 50 % overlap at 55 km/h

X time [ms]

Y acceleration [g]

Figure 4 — Acceleration crash pulses of two different crashes with identical Δ*v* and EES

5.2 Crash pulse definitions

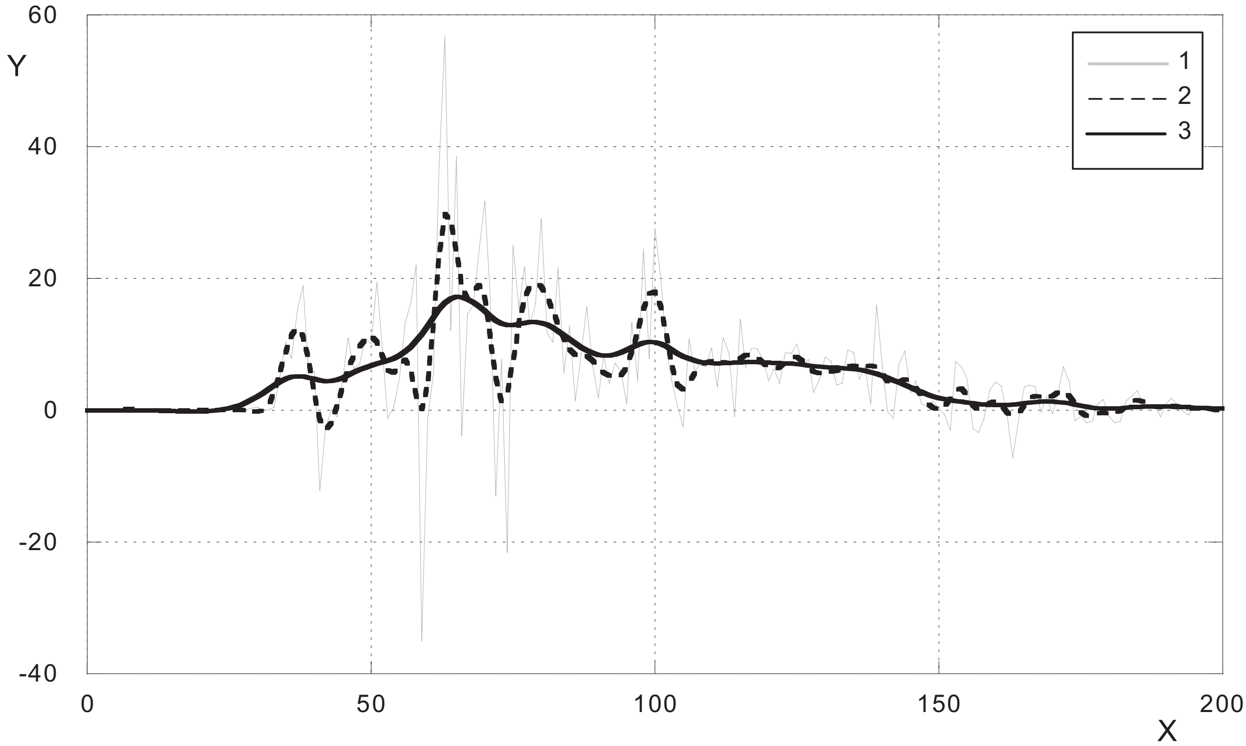
5.2.1 General

According to ISO 12353-1, the crash pulse is defined as the acceleration-time history during the impact phase.

NOTE It is also common to refer to the Δ*v*-time history as the crash pulse.

5.2.2 Sampling and filtering

The general recommendation (according to ISO 6487 and SAE J211-1) is that the sampling frequency should be at least ten times the channel frequency class applied, e.g. a CFC60 filter can be applied to a sampling frequency of 600 Hz or higher. According to SAE J211-1, CFC60 should be applied to vehicle crash acceleration data. A filtering example is shown in Figure 5, where a curve showing CFC60 and CFC20 filtering of the same pulse has been applied. The CFC20 filtering will also be used in 5.2.3.3.



Key

1 original unfiltered acceleration data (1000 Hz)

2 CFC60 filtered (60 Hz 4 pole Butterworth)

3 CFC20 filtered (20 Hz 4 pole Butterworth)

X time [ms]

Y acceleration [g]

NOTE Each level of filtering / averaging contains less information.

Figure 5 — Effects of different filtering applied to an acceleration crash pulse

5.2.3 Determination of beginning (t_0) and end (t_{end}) of crash pulse

In many cases (for example for the determination of mean acceleration) it is crucial to define when the crash pulse actually starts and ends, and very often this can be hard to determine.

The start and end of the crash pulse need to be determined in different ways depending on the data available.

The definitions of t_0 and t_{end} could be determined either with respect to the crash pulse characteristics or with respect to characteristics of derived measures such as Δv. Either of the following methods is recommended according to this Technical Report.

NOTE See Annex E for calculation processes related to the respective methods.

5.2.3.1 Method A: Determination based on Δ*v* – time history

This method is consistent with the determination of t_0 and t_{end} according to SAE J1698-1, referenced in 49 CFR Part 563 for continuously running algorithms. Using time of deployment will not allow an appropriate determination of t_0.

Definition of t_0: Time when the cumulative Δ*v* of over 0,8 km/h is reached within a 20 ms time period in the longitudinal direction for a frontal/rear event, or within a 5 ms time period in the lateral direction for a side impact event. See Figure 6.

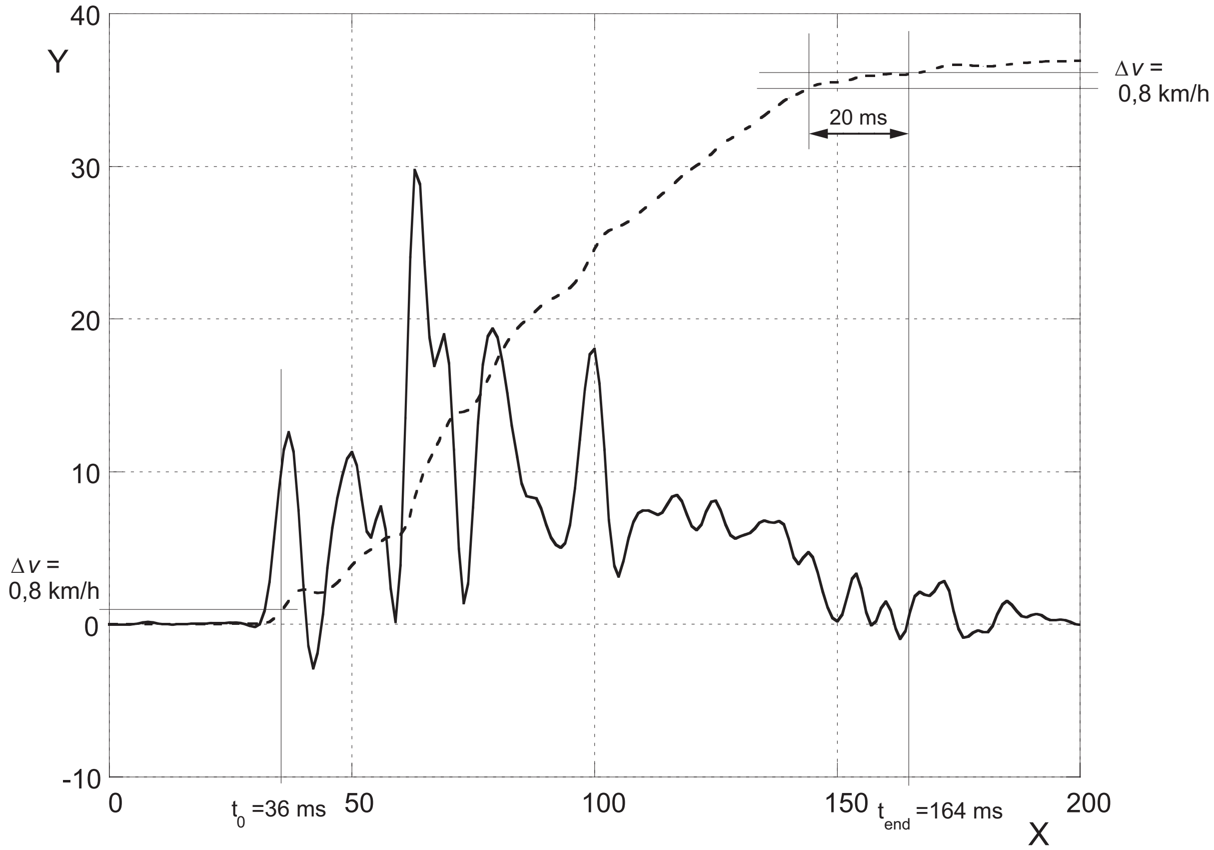
NOTE 1 According to 49 CFR Part 563, for systems with wake-up occupant protection control algorithms, the time at which the occupant protection control algorithm is activated may be used to define t_0.

Definition of t_{end}: Time where the end of an impact event (t_{end}) is at the moment when the longitudinal, cumulative Δ*v* within a 20 ms time period becomes 0,8 km/h or less.

NOTE 2 If t_{end} was not captured, the time to maximum Δ*v*, if available, may be substituted for t_{end} when a) the recorded crash pulse time-history is truncated (cut short) before meeting the 0,8 km/h change of velocity within 20 ms criterion, and b) the time to maximum Δ*v* is longer than the truncated crash pulse recording time period. The same logic is applied to side and rear impact events.

NOTE 3 In special cases, it may be possible to draw sufficiently secure conclusions from the acceleration-time history curve so that t_0 and/or t_{end} can be determined directly. Examples showing determination of t_0 and t_{end} for specific crash pulses are given in Annex E.

NOTE 4 Special attention has to be drawn to this when there are multiple impacts or more than one crash pulse in a crash sequence.



Key

X time [ms]

Y acceleration [g], change of velocity [km/h]

NOTE This figure shows Method A applied to a longitudinal crash pulse.

Figure 6 — Definition of t_0 and t_{end}, Method A

5.2.3.2 Method B: Determination based directly on acceleration – time history

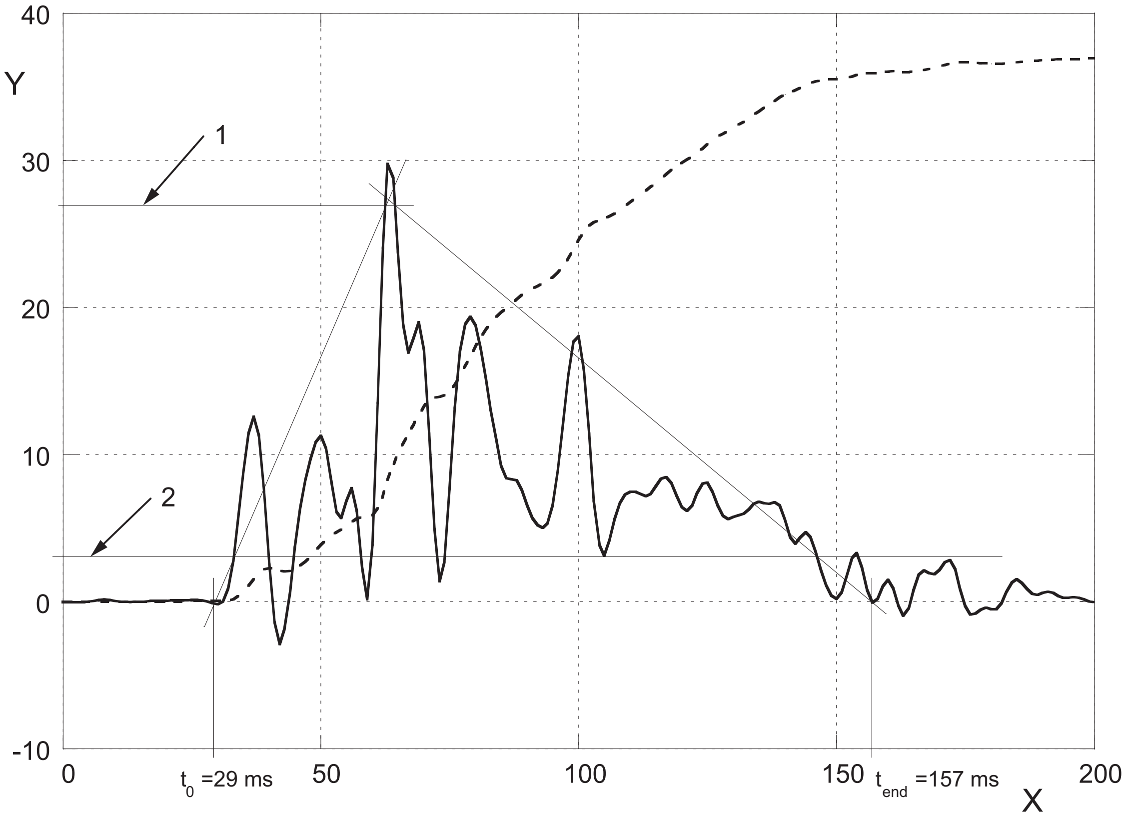
This method directly uses a CFC60 filtered acceleration pulse, see Figure 7.

Draw one line representing 10 % of peak acceleration, and another line representing 90 % of peak acceleration. Determine the intersections of the crash pulse and the above lines. This will form a triangle.

Definition of t_0: Time where the left intersection line meets the zero line.

Definition of t_{end}: Time where the right intersection line meets the zero line.

NOTE For some acceleration pulses it is not obvious if the first or a later intersection should be used. Below a later intersection is shown. In case of doubt, Method C can be used.



Key

1 90 % of peak acceleration (CFC60 filtered acceleration pulse)

2 10 % of peak acceleration (CFC60 filtered acceleration pulse)

X time [ms]

Y acceleration [g], change of velocity [km/h]

NOTE This figure shows Method B applied to a longitudinal crash pulse.

Figure 7 — Definition of t_0 and t_{end}, Method B

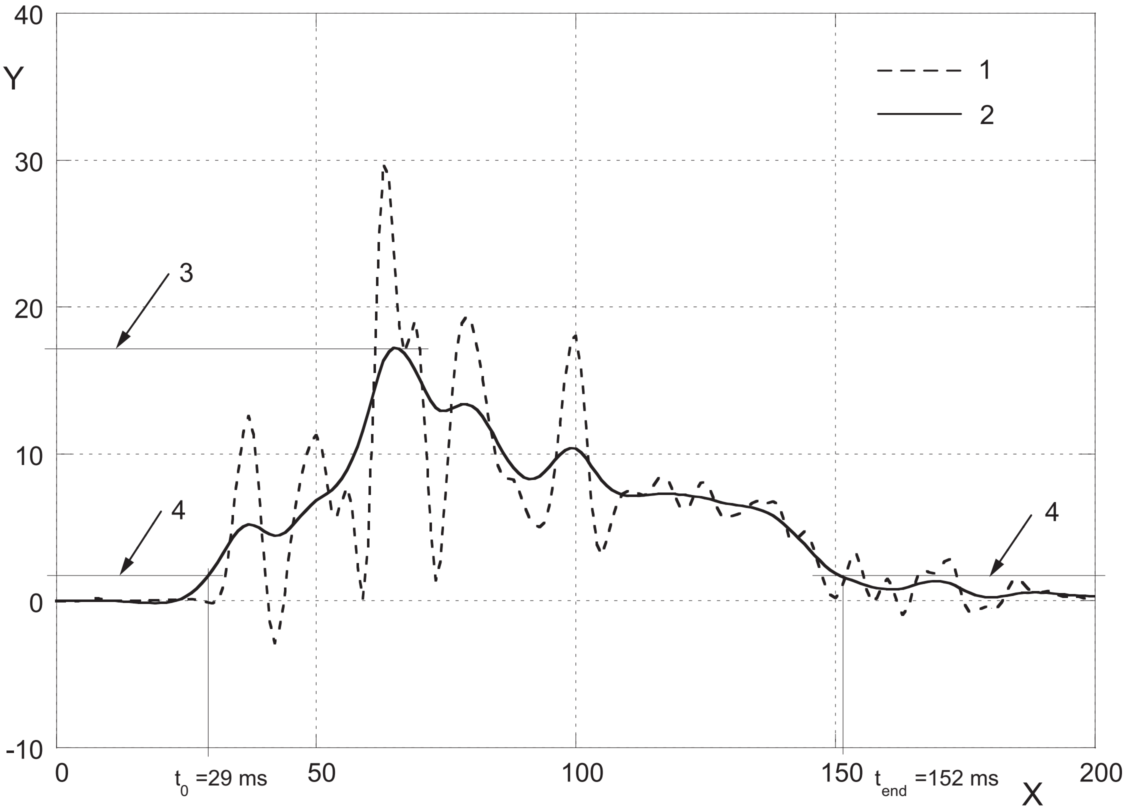
5.2.3.3 Method C: Determination based on application of a low filter frequency

Apply a CFC filter frequency of 20 Hz to the recorded acceleration pulse, see Figure 8.

Draw one line representing 10 % of peak acceleration. Determine the intersections of the acceleration pulse and the above line.

Definition of t_0: Time where the 10 % peak acceleration line meets the CFC20 filtered acceleration pulse to the left.

Definition of t_{end}: Time where the 10 % peak acceleration line meets the CFC20 filtered acceleration pulse to the right.



Key

1 CFC60 filtered acceleration pulse
2 CFC20 filtered acceleration pulse
3 peak acceleration of CFC20 filtered acceleration pulse
4 10 % of peak acceleration of CFC20 filtered acceleration pulse
X time [ms]
Y acceleration [g], change of velocity [km/h]

NOTE This figure shows Method C applied to a longitudinal crash pulse.

Figure 8 — Definition of t_0 and t_{end}, Method C

5.2.4 Calculation of acceleration resultant for an angled impact

If multiple directions (x, y, z) are recorded, a resultant acceleration value can be calculated at any time during the impact phase:

$$a_{res} = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

Relevant resultant values for Δv and mean acceleration can only be established by calculating Δv and mean acceleration separately for each direction, and then using the formula for calculating the resultant:

$$\bar{a}_{res} = \sqrt{\bar{a}_x^2 + \bar{a}_y^2 + \bar{a}_z^2}$$

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

5.3 Derived severity measures from crash pulse recorder output data

5.3.1 General

This clause describes the acceleration-related and velocity-related measures that can be directly derived or calculated from the crash pulse recorder output data.

5.3.2 Mean acceleration

The mean acceleration is calculated with respect to Δt ($a_{mean} = \Delta v/\Delta t$), between t_0 and t_{end}.

5.3.3 Peak acceleration

Crash pulse should be CFC60 filtered. Identify the peak acceleration value during the pulse duration.

NOTE Peak acceleration is affected by the sampling frequency and the subsequent filtering.

5.3.4 Δ*v* (maximum cumulative Δ*v*)

5.3.4.1 Methodology to derive Δ*v* from recorded data

a) From acceleration-time history:

— If crash pulse is complete, integrate acceleration-time history over the full duration;

— If crash pulse is truncated or incomplete, an appropriate acceleration-time-history curve fitting model (e.g. a third degree polynomial, trigonometric, or a geometric) may be applied to extend crash pulse to predict the total pulse length before the integration. Such extensions must however be applied with great care and must be related to other evidence supporting the extension. See Annex A for more information.

b) From Δ*v*-time history:

Required minimum recording frequency is 100 Hz. If crash pulse is complete, select Δ*v* at the end of the impact phase.

Annex A
(informative)

Extended application and calculations of impact severity parameters

A.1 Extended application of basic impact severity parameters

A.1.1 Maximum average acceleration over a specified time interval

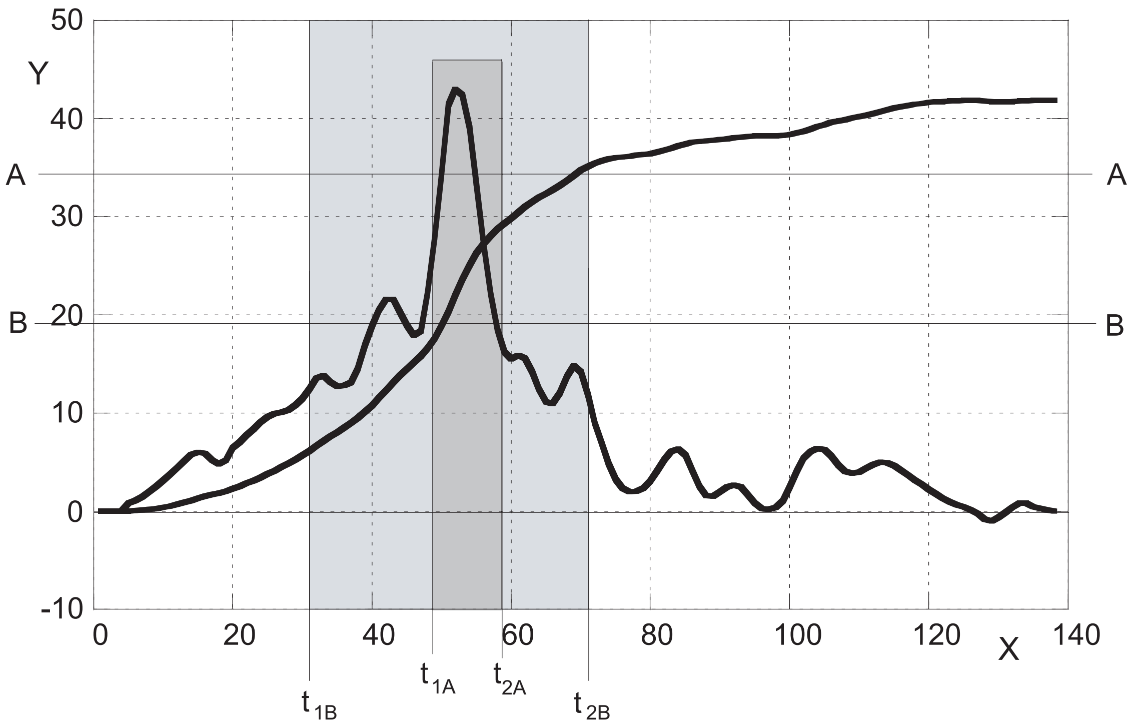
The average value of the acceleration *a(t)* over the interval t_1 to t_2 is given by

$$\bar{a} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)dt$$

A fixed time frame (window), e.g. 40 ms or 80 ms duration, can be used. The window is applied where the maximum mean acceleration for the specific window size is found.

NOTE A very narrow window will approach the peak acceleration. A wide window will approach the mean acceleration.

Use of different window sizes is illustrated by Figure A.1.



Key

A maximum average over 10 ms window size: 34,0 g
B maximum average over 40 ms window size: 19,8 g
X time [ms]
Y acceleration [g], change of velocity [km/h]

Figure A.1 — Illustration of maximum average over a specified time interval

A.1.2 ASI — Acceleration Severity Index

ASI is used in the evaluation of performance of barriers and roadside equipment/installations in crashes with vehicles in accordance with EN 1317-1.

Maximum value of ASI (t) plot obtained from vehicle Centre of Gravity accelerations (x, y, z)

$$\mathrm{ASI}(t) = \sqrt{\left(\frac{\bar{a}_x}{12}\right)^2 + \left(\frac{\bar{a}_y}{9}\right)^2 + \left(\frac{\bar{a}_z}{10}\right)^2}$$

where $\bar{a}_x, \bar{a}_y, \bar{a}_z$ are the filtered components of the vehicle acceleration.

To calculate the average acceleration components, a maximum average of the same 50 ms window is used (in a similar way as described in A.1.1).

NOTE An ASI value can be calculated with at least one of these components.

A.1.3 Influence of several crash pulse characteristics

Several crash pulse characteristics may be taken into account in combination to better explain the occupant response. Some examples are listed below:

— peak acceleration combined with time to peak acceleration;

— mean acceleration combined with peak acceleration;

— Δv combined with crash pulse duration.

NOTE Some examples are included in B.2 and D.2.

A.1.4 VDC — Theoretical Occupant Contact Velocity

A.1.4.1 Objective

VCD (in formulas v_{CD}) is a Δv metric focused on the early portion of the crash pulse that is more critical to the crash severity experienced by an occupant. Abrupt crash pulses or early peak-g's (e.g. full-frontal barrier) have notable higher crash severity than a soft pulse or late peak-g (e.g. angle impact) with the same Δv or peak-g. VCD rates abrupt crash pulses and early peak-g's with a higher severity measure.

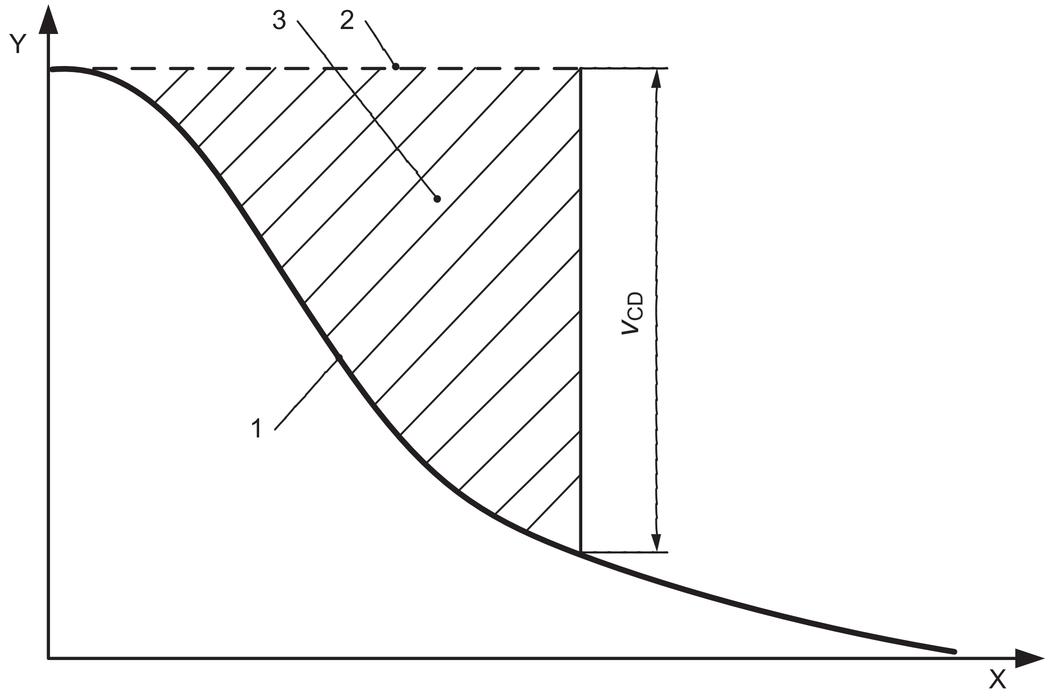
VCD defines impact severity in terms of a theoretical unrestrained occupant contact velocity based on crash event Δv-time history data. VCD relates to chest contact velocity and gives a theoretical measure of the occupant energy that must be managed by the restraint system for a given pulse.

A.1.4.2 Method

VCD gives the theoretical driver chest to steering wheel hub contact velocity of an unrestrained occupant with an initial distance (D). It can be calculated from all recorded vehicle v-t pulses.

Construct the vehicle v-t pulse from the crash pulse recorder or EDR data. Define a standard distance, D, as the distance between the driver's chest (50th percentile male) and the steering wheel hub. A suitable value is 300 mm. Once a value for D is defined, use it for all vehicles and all recorded v-t pulses to be compared. Next, assume that the driver is unrestrained and travels at the vehicle velocity, v_0, until the driver has travelled the distance D.

The theoretical contact velocity, v_{CD}, is calculated by numerical integration from the v-t curves of the vehicle and the driver until the cumulative value of D is reached, as shown in Figure A.2. v_0 is not required to do the integration.



Key

1 vehicle, v-t

2 unrestrained driver, v-t; v_0

3 *D*; area between driver and vehicle v-t curves

X time

Y velocity

NOTE v_{CD} is driver to hub contact velocity, which is the measure of vehicle pulse severity.

Figure A.2 — VCD approach, principle

The choice of *D* determines two groups of crash pulses. In one group are the pulses where $v_{CD} < \Delta v$ of the crash (as illustrated in Figure A.2). The second group are the pulses where $v_{CD} = \Delta v$ of the crash. The distribution of pulses between the two groups depends on the choice of *D*.

A.1.5 VPI — Vehicle Pulse Index

A.1.5.1 Objective and description

The Vehicle Pulse Index (VPI) is a metric that can be used to assess the relative severity of a crash pulse to a restrained occupant. This metric utilizes a Single Degree of Freedom (SDOF) model as a processing tool.

The model consists of a mass (M) representing the occupant, a spring (k) and a slack (s) representing the restraint system. The restraint stiffness value and slack can be assigned by the user. The input is the vehicle body motion $x(t)$ (derived from a crash pulse recorder or an EDR) and the output is the calculated y acceleration pulse associated with the occupant mass.

By solving the equation of motion for the mass M, VPI is defined as the maximum value of the calculated occupant mass acceleration, i.e.:

$$M\ddot{y} + ky = P(t)$$

where

$$P(t) = \begin{cases} 0, & x < s \\ k(x - s), & x \geq s \end{cases}$$

$$VPI = \max(\ddot{y})$$

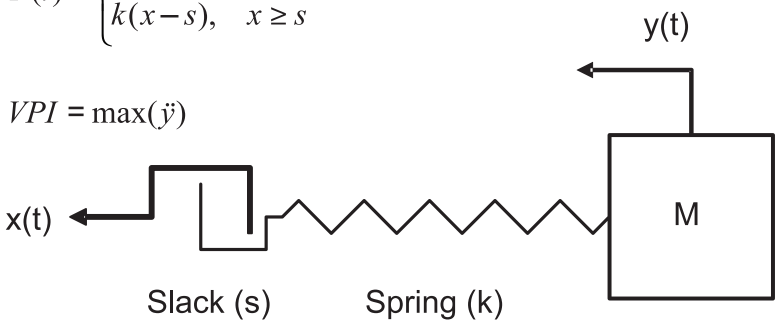


Figure A.3 — SDOF VPI model

As the output of the model depends on the characteristics of the spring and the amount of slack, it is recommended to select fixed values for these parameters and only vary the pulse input to calculate the VPI for different crash pulses.

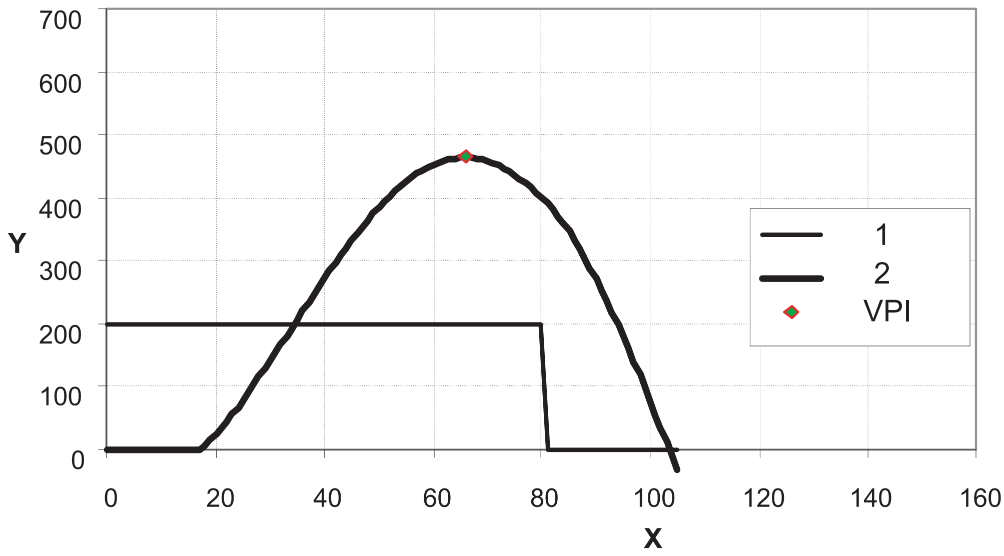
With a mass of 1 kg recommended values are: k = 2500 N/m, s = 0,03 m.

A.1.5.2 Calculation examples

A.1.5.2.1 Example 1: Constant pulse

Crash pulse: Constant 200 m/s^2 for 80 ms. Result: VPI = 464,6 m/s^2 (47,4 g). See Figure A.4.

NOTE This may be a suitable pulse for checking the calculation algorithm.



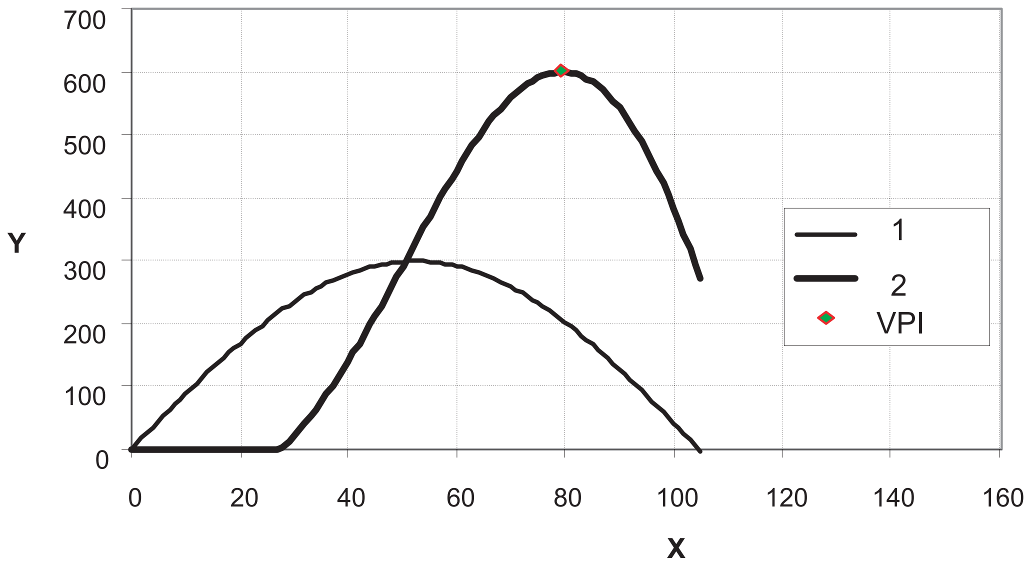
Key

1 acceleration input
2 response
X time [ms]
Y acceleration [m/s^2]

Figure A.4 — VPI calculation Example 1

A.1.5.2.2 Example 2: Sine pulse

Crash pulse: 300sin(30t) m/s^2 for 105 ms. Result: VPI = 600,9 m/s^2 (61,3 g). See Figure A.5.



Key

1 acceleration input

2 response

X time [s]

Y acceleration [m/s^2]

Figure A.5 — VPI calculation Example 2

A.2 Derived surrogate acceleration pulse from cumulative Δ*v*-time history

A.2.1 Background

Event data recorders may only report Δ*v*-time history. Therefore a process to convert this data to an acceleration-time history is useful. Since this is a differential process over discrete time intervals the derived pulse will not contain all the features and the resolution of a directly measured acceleration-time history. The acceleration pulse derived from the lower resolution EDR data may also have a time lag.

There can be variations in an EDR's crash pulse reporting rate and duration. However, US market vehicles manufactured on or after September 1, 2012 equipped with an Event Data Recorder function should comply with the United States Code of Federal Regulation, 49 Part 563 – Event Data Recorders. The Part 563 rule standardizes the minimum required data elements including the longitudinal Δ*v*-time history. Minimum required reporting intervals and sampling rates are:

— 0 to 250 ms, or 0 to End of Event Time plus 30 ms, whichever is shorter;

— 100 Hz sampling rate.

A.2.2 Methodology

When only a Δ*v*-time history is available from an EDR report, an acceleration-time history can be calculated from the provided Δ*v*-time history by differencing the incremental change of velocity over the associated time increment to obtain a coarse acceleration-time history.

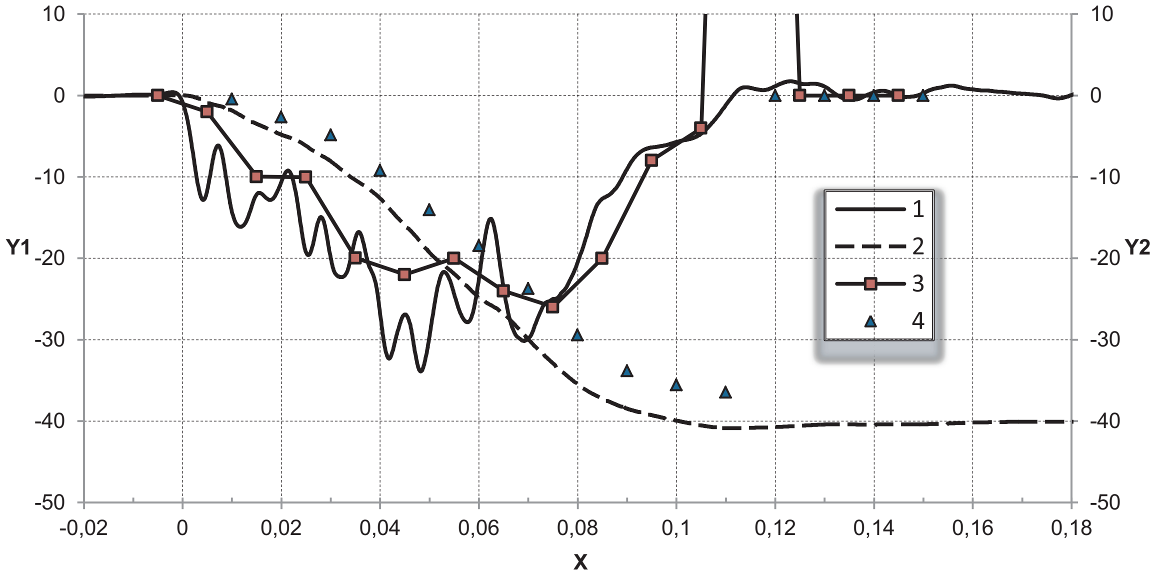
$$a = \frac{dv}{dt} = \frac{v_{i+1} - v_i}{\Delta t}$$

The computed acceleration is plotted at the midpoint between time *i* and *i*+1.

A.2.3 Application example

Data from NHTSA NCAP test 4445 is used in this application example. The usual array of accelerometers in an NCAP test recording data at 1000 Hz captured this impact. This data along with the EDR reports can be obtained via the NHTSA's website at http://www.nhtsa.gov.

The acceleration-time history, recorded at 1000 Hz and filtered according to CFC60, and velocity time history are plotted in Figure A.6. The EDR data concurrently recorded at 100 Hz during this crash test is plotted in Figure A.6 as well. For example purposes the above equation was applied to the EDR data and the associated lower resolution EDR derived acceleration pulse is plotted and compared to the higher resolution accelerometer data, depicted in Figure A.6.



Key

1 acceleration-time history (1000 Hz CFC60)
2 Δ*v*-time history (1000 Hz CFC60)
3 calculated surrogate acceleration pulse from EDR Δ*v* output data
4 EDR Δ*v* output
X time [s]
Y1 acceleration [g]
Y2 change of velocity [mph]

Figure A.6 — Crash test acceleration and velocity compared to the EDR data in NHTSA test 4445

NOTE 1 There is an obvious (dramatic) spike in the derived acceleration pulse after 110 ms. This EDR stores up to 50 ms before deployment and 100 ms after deployment. Because the airbag is deployed near 10 ms into the pulse, the total recording duration is 110 ms. Data after 110 ms is default data (all zero) and the calculation process is stopped at 110 ms. If it was not ignored, the analyst would reach the wrong conclusion that there was a positive 36 G acceleration at between 110 ms and 120 ms, which is a higher numerical value than the negative G's in the real crash pulse.

NOTE 2 The pulse derived from the lower resolution EDR data under-reports the actual values and there may be a time lag.

A.3 Comparison of characteristics calculated from recorded Δ*v* and acceleration

A.3.1 Introduction

Controlled barrier crashes run in laboratories and specialized test fleets often have extensive instrumentation that can measure X, Y and Z acceleration at 1 ms or less intervals that allow methods A, B and C to be used to characterize the beginning and end of a crash pulse. There are also many real world crashes where a vehicle event data recorder may be the only instrumentation available. While some of these data recorders may record acceleration data at high frequencies similar to barrier test instrumentation, many only record longitudinal X (or X and Y) Δ*v* at 10 ms intervals.

Using the 10 ms Δ*v* intervals to derive a surrogate acceleration pulse has been discussed in A.2. This surrogate acceleration pulse is effectively much more heavily damped than the CFC60 filter typically used on higher frequency instrumentation data. The heavy damping will reduce any sharp peaks in the CFC60 data substantially, such that it is inappropriate to compare a peak acceleration value from CFC60 data with a surrogate derived peak acceleration value from an EDR.

Annex F illustrates high frequency CFC60 data versus EDR data derived from the raw acceleration data used to generate the CFC60 data. A different metric is needed to be able to compare some measure of peak acceleration between these pulses.

A.3.2 Peak surrogate acceleration

For the recorder which has only Δ*v* at 10 ms intervals, the surrogate acceleration calculated for each 10 ms interval as described in A.2 can be compared and the peak value selected.

A.3.3 Peak 10 ms rolling average acceleration

The peak surrogate acceleration selected in A.3.2 should not be compared directly to the peak acceleration from higher frequency data. Higher frequency data with only a CFC60 filter applied must be more heavily damped to be comparable to the EDR surrogate acceleration pulse. Any number of different heavier filters could be used.

It is possible to take a set of 1 ms interval acceleration data and estimate when an airbag “wakeup” deployment algorithm would have triggered, or to use the US 49 CFR Part 563 definition of the start of an event for continuously running algorithms (Method “A”). The data could be processed to duplicate the function of an EDR, calculating the Δ*v* for each 1 ms interval and accumulating it and reporting it at 10 ms intervals. However, selecting the start point and doing the accumulation is a relatively complex calculation. A simpler measure, one that lends itself to automated calculations, is needed.

One of the simple measures is to take the 10 ms rolling average of the 1 ms CFC60 data. The peak value of this more heavily damped parameter should approximate the peak values that would be obtained from an EDR surrogate acceleration pulse.

Since the 10 ms rolling average would be calculated every 1 ms, and the EDR reports only every 10 ms, it is possible that the rolling average will still catch a slightly higher peak value than the EDR. Since the EDR is processing raw data, not CFC60 filtered data, it is also possible that there could be some random variations where the EDR peak value could be higher than the 10 ms CFC60 rolling average. However, for the purpose of comparing large data sets these variations are relatively small and can be considered negligible on an aggregate basis.

The instantaneous 10 ms rolling average acceleration can be described as:

$$A_{10\text{ms avg } x} = (A_{x-5} + A_{x-4} + A_{x-3} + A_{x-2} + A_{x-1} + A_{x} + A_{x+1} + A_{x+2} + A_{x+3} + A_{x+4})/10$$

A.4 Handling of truncated pulses

A.4.1 Introduction

There are instances when the on-board crash pulse recorder does not capture the complete acceleration crash pulse. This may be as a result of the design and configuration of the crash pulse recorder, the result of power failure, insufficient memory, or electronic components being compromised. A method to extrapolate the truncated crash pulse acceleration data in order to derive a surrogate maximum Δv for statistical comparison of accidents has been developed. This method is recently explored by some experts and needs to be further verified (see e.g. References[6],[8]). The method utilizes analytical crash pulse modelling, vehicle specific crash performance data, and specific crash related data.

This method may be applicable if the recorded part of acceleration crash pulse is long enough to indicate that its shape can be represented by a certain model shape, its maximum values are well passed over and the pulse duration can be estimated.

A.4.2 Methodology

Given a significant portion of the acceleration-time history, the objective is to extrapolate the missing data to derive a surrogate maximum Δv value for statistical comparison of accident using constraints that best reflect the characteristics of the subject crash. In order to apply these constraints, a mathematical model for the pulse under study must first be developed. Once the shape is determined, the measured vehicle deformation, crash dynamics information, pulse duration, physics based determinations of velocity changes and other known parameters can be utilized to scale the chosen pulse shape to the crash under study.

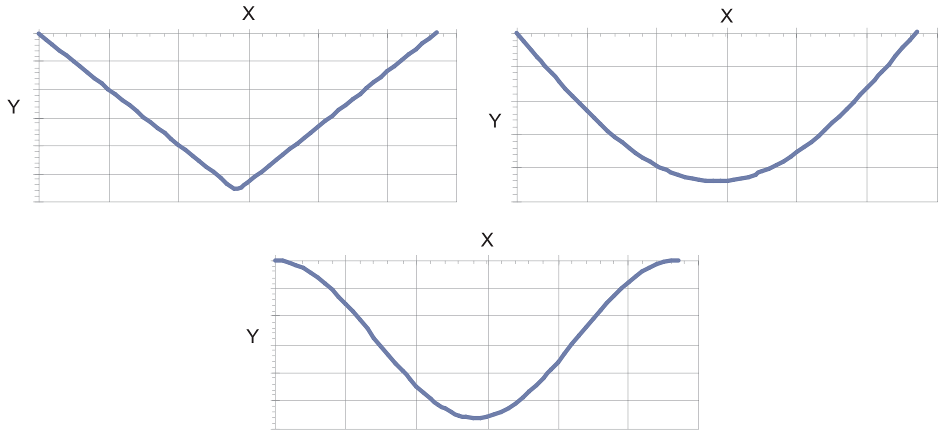
A mathematical model to represent the incomplete crash pulse recorder recorded acceleration profile is selected. The requirement for the chosen mathematical model is that it is integrable either in closed form or numerically. The simplest approach is to use an integrable geometric or trigonometric function such as a square, triangle (bi-linear), sine, haversine or similar function which allows a closed form solution. The better the selected function matches the shape of the available portion of the acceleration crash pulse the better the resulting reconstructed data will be. The need for the function to be integrable is necessary in order to apply the available constraints.

The portion of the subject acceleration crash pulse under analysis or staged collision test data of the same vehicle should be used as the basis to choose the mathematical function or pulse shape that will be used as a basis for the reconstructed continuation of the truncated collision pulse.

After the pulse shape is selected it must be constrained or scaled to fit the provided pulse data. This scaling is dependent on the information available. The mathematical model's primary features are shape, duration, and peak. Additionally, the integration of this model yields a velocity time history along with a total velocity change (Δv), and the second integration yields a displacement time history and the associated mutual deformation (crush) of the collision partners. These integrations are useful constraint parameters and can be utilized to scale the reconstructed crash pulse. Collision scene information can be utilized for a momentum solution for the crash which can yield total velocity change (Δv). This momentum derived velocity change can be compared to the first integral of the chosen collision acceleration pulse shape as a constraint. Measurements of the vehicle deformation can be performed to yield mutual crush which can be then related to the second integral of the chosen collision pulse shape. The availability of supplemental crash pulse recorder data can include information (e.g. total Δv) that may be utilized in evaluating and scaling the reconstructed crash pulse.

A.4.3 Sample pulse shapes

Previous research has developed various pulse shapes, three sample pulses are shown. While simple geometric and trigonometric functions are shown in Figure A.7, it is possible to apply more complex functions or use a numerical method.



Key

X time [s]

Y acceleration [g]

Figure A.7 — Sample geometric pulse shapes (triangular, sinusoidal and haversine)

A.4.4 Application example

The available constraint data will depend on the crash type, vehicle type, crash pulse recorder type along with the collected information from the crash investigation. Since the exact process can vary depending on the available information, this example may not be representative of every reconstruction.

This example involves an incomplete or truncated crash pulse recorder collision acceleration pulse for a striking vehicle in a front-to-side car-to-car impact. The constraint data includes the truncated velocity time profile, the assumption that momentum is conserved and the measured vehicle deformation.

The vehicles were measured and scale drawings were prepared. The impact configuration is depicted in Figure A.8. The scale diagrams of the vehicle crush profiles facilitate the determination of the mutual crush at about 44 inches (1,1 m). The mutual crush, in this example, is the difference of the distance between the two CG's at maximum engagement and initial contact.

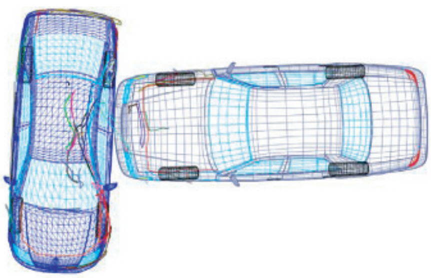
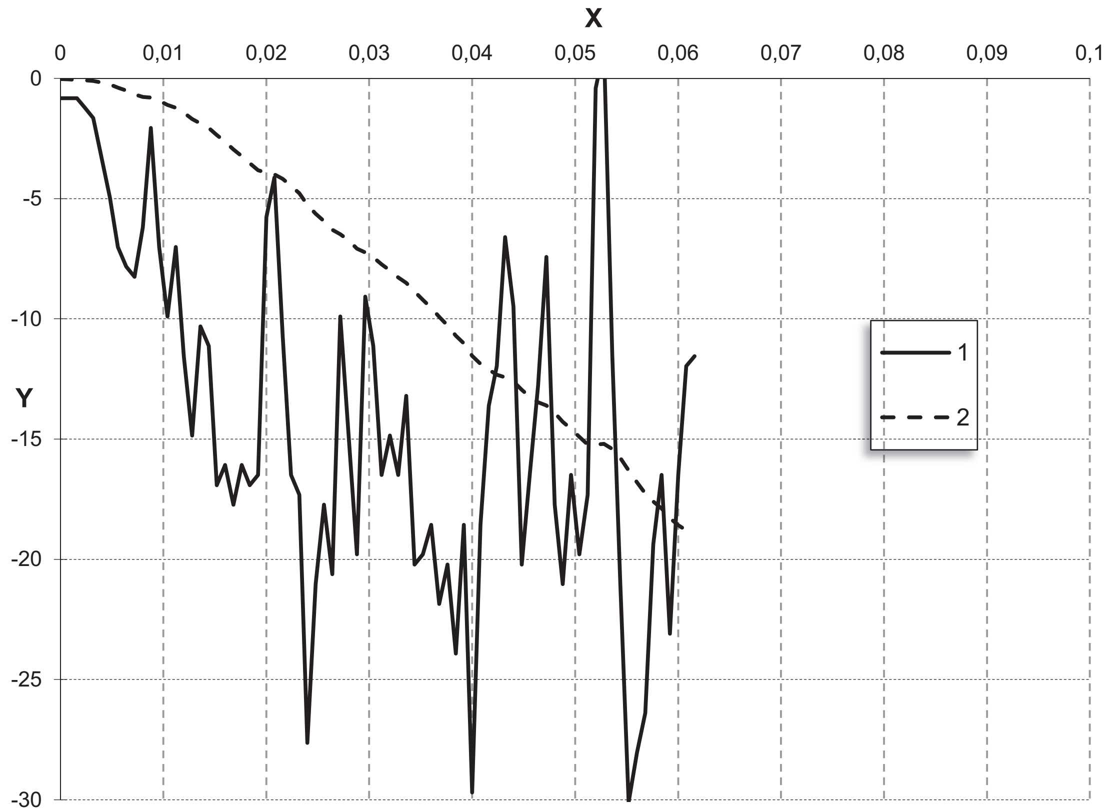


Figure A.8 — Impact configuration

The striking car crash pulse recorder was downloaded and the collision pulse examined. The crash pulse recorder data from the striking vehicle is incomplete, see Figure A.9. This can be seen as the acceleration data does not return to zero and the velocity change is continuing to increase at the end of the pulse. The integration of this data indicates a velocity change (Δv) of 18,8 mph (30,3 km/h). Since the pulse is clearly truncated, the 18,8 mph (30,3 km/h) integration of the incomplete pulse is an under-representation of the Δv.



Key

1 acceleration-time history (incomplete)

2 Δ*v*-time history (incomplete)

X time (s)

Y acceleration [g] and change of velocity [mph]

Figure A.9 — Incomplete crash pulse recorder data recorded during the crash

A review of the recorded partial pulse and its integral indicates that a sinusoidal pulse is an adequate shape for the model. While a sinusoidal pulse models the integration (velocity profile) of the recorded acceleration pulse well, due to the method's limitations it does not capture individual peaks in the acceleration profile. If there is a good model fit for the recorded signal part, then the method assumes a good model fit for the truncated portion. Due to the limitations based on the selected pule shape the extrapolated pulse will not replicate a specific complete pulse. The mathematical representation for the sinusoidal pulse is:

$$a(t) = P \sin\left(\frac{\pi t}{T}\right)$$

$$v(t) = \frac{-TP\cos\left(\frac{\pi t}{T}\right)}{\pi} + t\left(v + \frac{TP}{\pi}\right)$$

$$s(t) = \frac{-T^2 P \sin\left(\frac{\pi t}{T}\right)}{\pi^2} + t\left(v + \frac{TP}{\pi}\right)$$

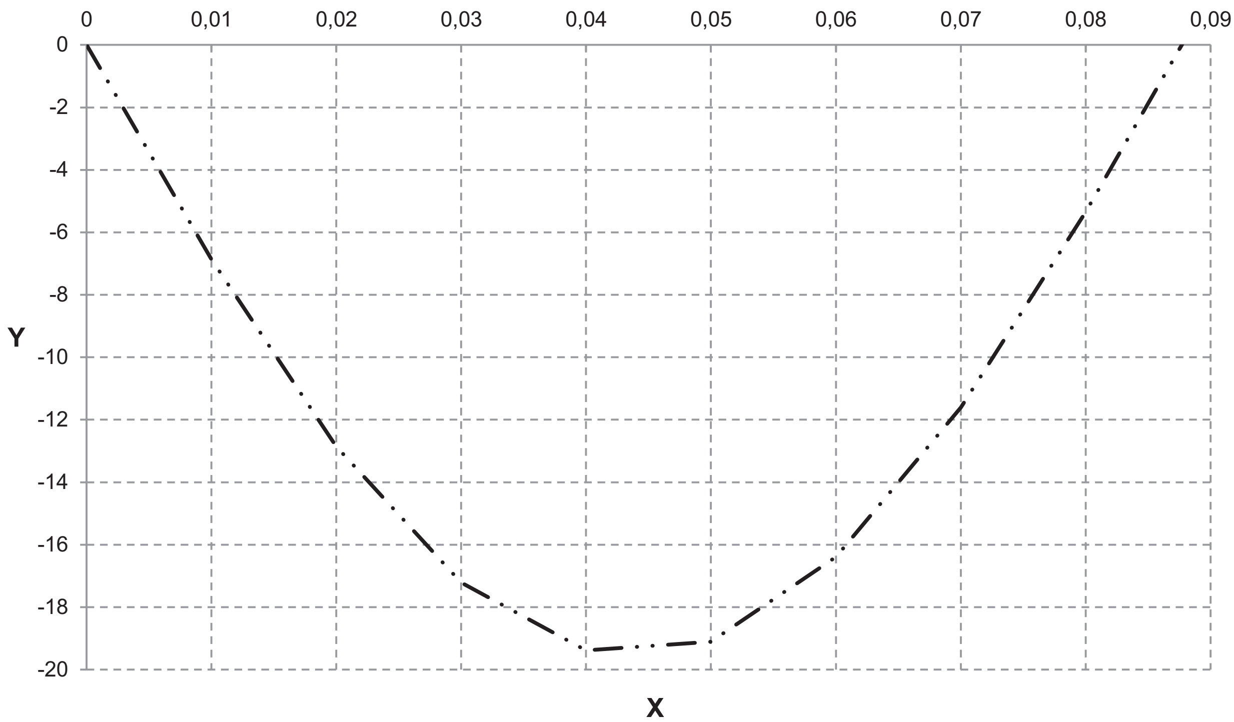
$$T = \frac{[mutual\ crush]}{\left[\left(v_{01} - v_{02}\right) + \left(\frac{\Delta v_1}{2} - \frac{\Delta v_2}{2}\right)\right]}$$

where

- a is the acceleration;
- v is the velocity;
- t is the time;
- s is the displacement;
- P is the peak acceleration;
- T is the pulse duration.

As can be seen in the equation for *a(t)*, the calculation requires the determination of pulse duration, *T*. A momentum solution provides a physics based determination of initial or closing vehicle speeds prior to impact and vehicles overall Δ*v*. As indicated previously, vehicle measurements and scale vehicle analysis allows the determination of the mutual crush. These factors are utilized to generate a plot of the models output time histories and compare them to the crash pulse recorder recorded partial pulse.

Based on the provided data, a surrogate pulse duration *T* can be calculated, thus *a(t)* can be defined and plotted, see Figure A.10.



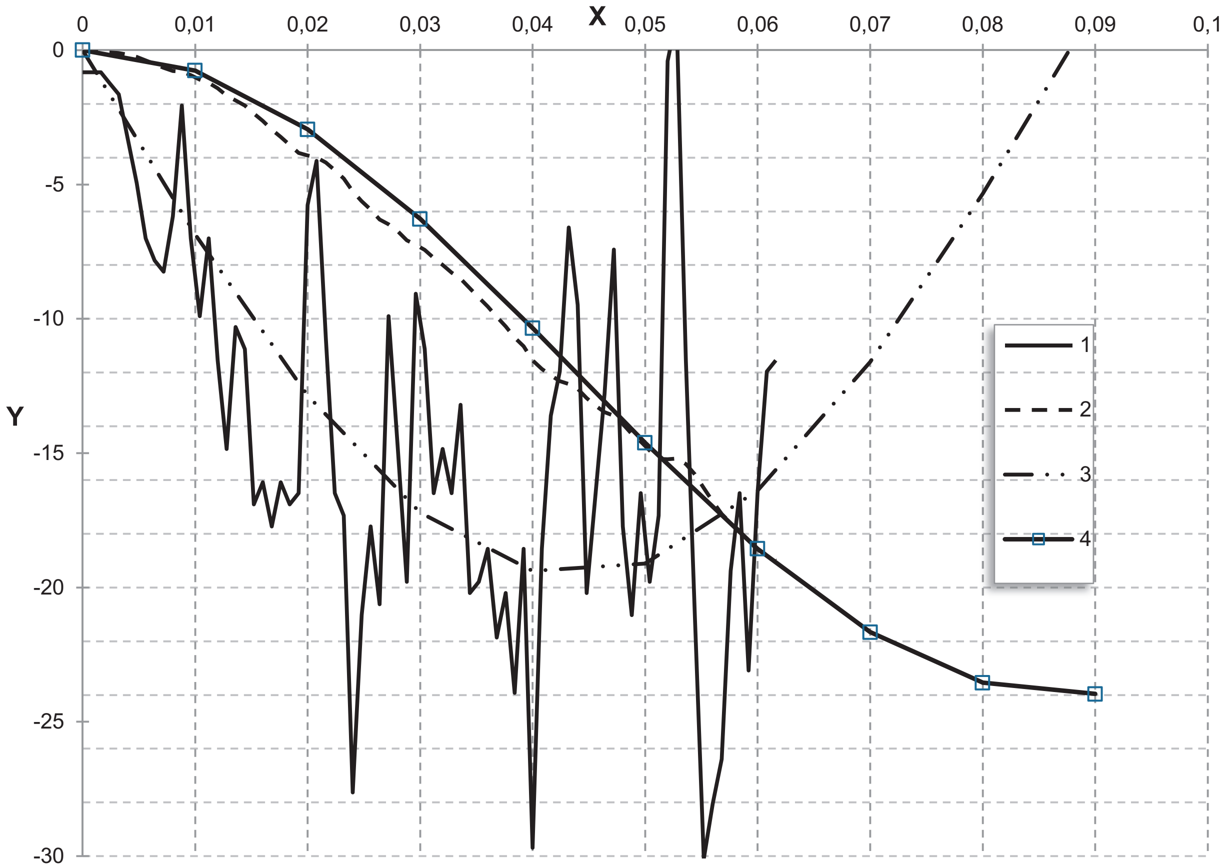
Key

X time [s]

Y acceleration [g]

Figure A.10 — Sine acceleration pulse plotted at the midpoint of the Δ*v* range

An iterative process may be used to refine the model inputs due to the inherent uncertainty that will always be present in the momentum solution until the constraint values of the model velocity time history are sufficiently close to the crash pulse recorder partial velocity time history. Figure A.11 shows the crash pulse recorder data acceleration-time history (line 1) and the associated integration (line 2) with the derived sine model (line 3) and the associated velocity (line 4). Note that the model pulse does not capture the peaks and associated with the actual acceleration pulse but the derived velocity profile is similar. The acceleration curve can be evaluated at the time step of the recorded pulse to derive the estimated acceleration values that satisfy the constraints used for the missing portion of the pulse at the appropriate time step. The result of this investigation is a surrogate maximum Δ*v* = 24 mph (38,7 km/h).



Key

1 acceleration-time history (incomplete)

2 Δ*v*-time history (incomplete)

3 adapted sine approximation

4 completed surrogate Δ*v*-time history

X time [s]

Y acceleration [g] and change of velocity [mph]

Figure A.11 — Extrapolation of the Δ*v* signal to derive a maximum Δ*v* using the truncated acceleration pulse with a sine approximation model

Annex B
(informative)

Application and use of data recorded

B.1 Usefulness of crash pulse recorder data

Vehicle crash pulse recorder data enables us to use acceleration in crash reconstruction analysis. In ISO 12353-2 the advantage of using parameters derived from the acceleration-time history in crash reconstruction analysis was shown. In most cases, the acceleration-time history was the preferred measure. In this Annex the usefulness of studying the shape of the crash pulse is shown.

Vehicle crash pulse recorder data are useful for most planar crash types, while crash reconstruction computation programs typically exclude certain crash types such as, poles, deep sideswipes, underrides, etc. However, the available recorded impact severity data should be used to supplement a crash reconstruction based on other evidence, not supplant.

Traditionally it has only been possible to calculate Δv by using the physical laws of conservation which are the basis for different accident reconstruction programs used world-wide. But very often the knowledge about the necessary input data are incomplete or even incorrect. As a consequence, the result of Δv has a wide range of confidence and sometimes it is so incorrect that wrong conclusions are drawn. In contrast, Δv as a result of the integration of the crash pulse is as precise as the recording procedure is done (frequency of measuring points) but has still to be interpreted because of the vector character of Δv depending on the number of axes of the recorded acceleration.

It is also evident that in certain situations the stored data may not correspond to the actual situation. See Annex D for examples, including non-frontal impacts with significant rotational acceleration and incomplete recordings due to power loss.

B.2 Impact severity and influence on injury outcome

B.2.1 Influence on injury outcome

Historically, traffic accident research categorizes or classifies crashes, with some measure of impact severity as a highly useful element. Such measures that help characterize the crash pulse are of particular interest for research on occupant injury frequency and severity. Also, a recorded crash pulse is an impact severity measure that may be available for both laboratory crash tests and real-world accidents, thus providing a direct link between research and field experience.

As recorded crash pulse data becomes more commonly available in the vehicle fleet, there is an increased need for a common interpretation of that data to support global research. Consistent terminology and analytic methods will facilitate analysis across laboratory crash test facilities, as well as the integration of crash test and real-world crash data.

In ISO 12353-2, a matrix was elaborated on relevant impact severity measures related to common impact configurations. A general conclusion from that work was that in impacts where the intrusion plays a minor role, information from crash pulse data would provide a superior input for the determination of impact severity.

The next step would consequently be to investigate (given a crash pulse record) which of the parameters from the crash pulse would be the best link to injury causation – for the actual crash configuration, and ideally also related to body region.

B.2.2 Crash pulse contribution to research on human injury tolerance information

Knowledge from real-world crashes is important in the design of a crashworthy road transportation system. Such design must be based on the human injury tolerance limits. Links between impact severity and injury outcome could be helpful in understanding such tolerance limits. Traditionally impact severity has been calculated with retrospective reconstruction technique.

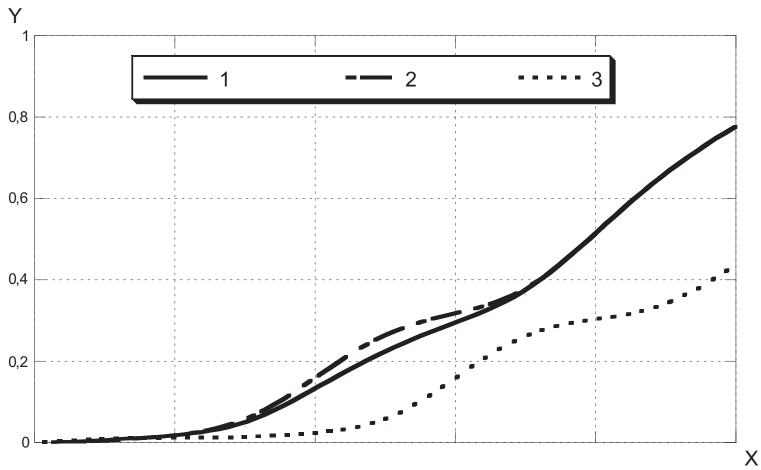
More recently, researchers have presented injury risk functions where impact severity has been measured with crash data recorders. Their aim was to present injury risk functions, calculated with crash pulse recorder data. These risk functions are calculated with statistical analysis and are based on aggregated data, and express the probability of injury as a function of crash severity recorded by the crash pulse recorder. They express the average injury risk of the vehicles included in the data set. They must not be used to predict injury outcome in a specific crash.

Although several parameters may influence the injury risk as illustrated in Figure B.1, these injury risk functions show the statistical correlation between crash pulse characteristics and injury risk.

Below are some examples of risk functions for various recorded or calculated crash severity parameters in frontal impacts (Figures B.1 and B.2). The injury severity is described by AIS or maximum AIS (MAIS). In most examples the risk of MAIS 2+ or MAIS 3+ injury is presented.

Figure B.1 presents an attempt to differentiate injury probability in frontal impacts for injuries to different body regions. The plot shows risk of AIS 2+ injury. At a given crash severity the injury risk may differ for injuries to different body regions. In the example the head injury risk is lower than the chest and leg injury risks.

The source of Figures B.1 to B.4 is the Folksam database of recorded frontal impacts.



Key

1 leg
2 chest
3 head
X crash severity
Y injury risk

Figure B.1 — Reported AIS 2+ rate by body region versus Δ*v* from crash pulse recorder data

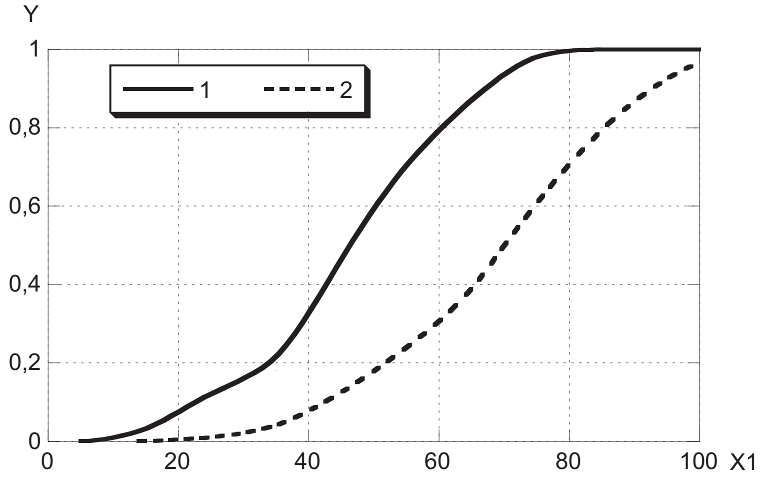
Figure B.2 shows risk of any MAIS 2+ and MAIS 3+ injury in frontal impacts at three crash severity parameters:

— change of velocity,

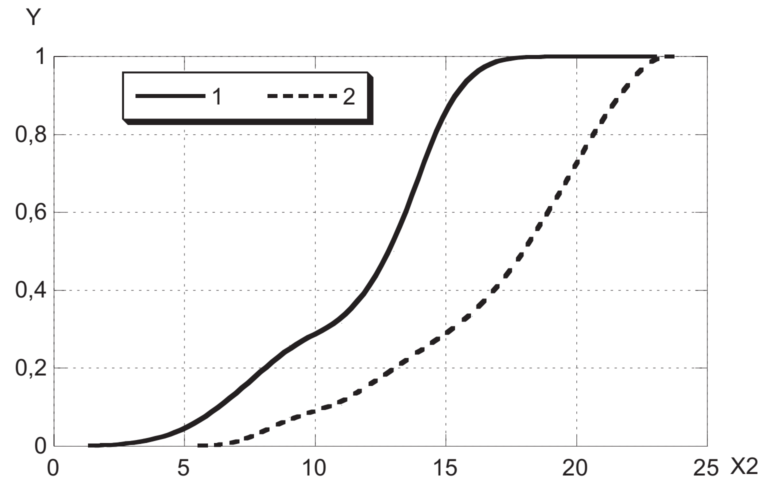
— mean acceleration, and

— peak acceleration.

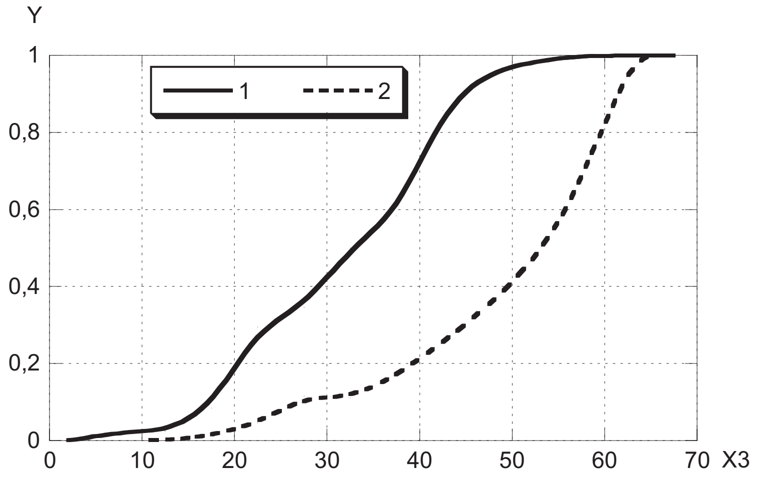
The figures show that all three parameters are influencing the injury risk.



a)



b)



c)

Key

1 MAIS 2+ injury

2 MAIS 3+ injury

X1 change of velocity [km/h]

X2 mean acceleration [g]

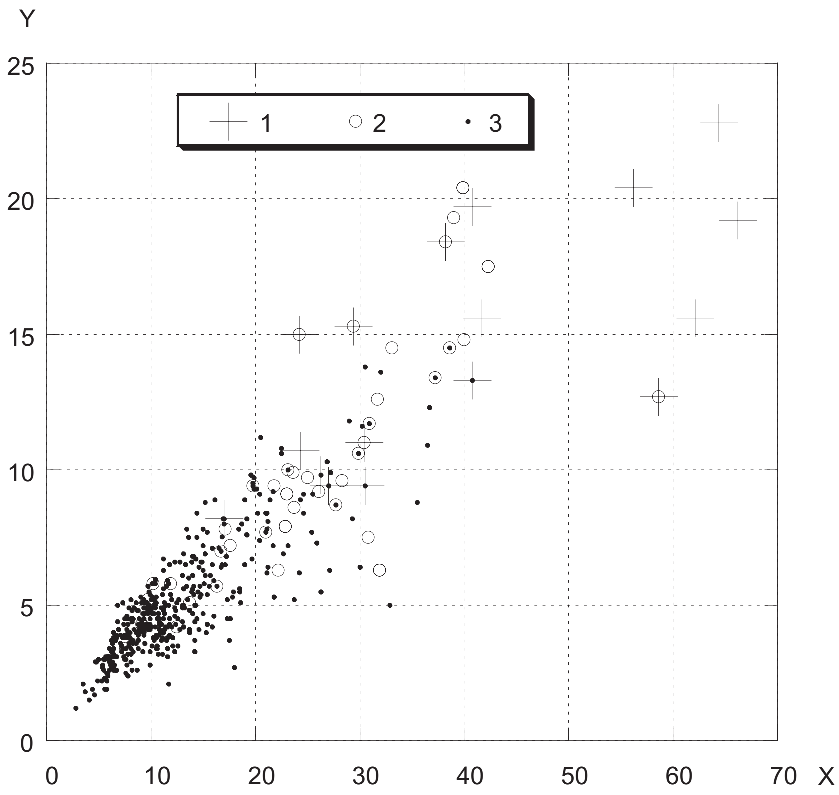
X3 peak acceleration [g]

Figure B.2 — Three impact severity metrics (change of velocity, mean acceleration, peak acceleration) vs. injury risk

Figures B.3 and B.4 below show injury AIS level (uninjured and MAIS 1, MAIS2, and MAIS3+) for occupants exposed to combinations of two crash severity parameters. Each point represents an occupant exposed to a combination of two crash pulse characteristics. It gives an indication of the influence of combinations of parameters.

Figure B.3 shows the influence of mean and peak acceleration and Figure B.4 the influence of mean acceleration and duration.

The figures indicate that high mean acceleration or high peak acceleration separately may influence the injury risk. In Figure B.4 it can be seen that pulse duration is not influencing injury risk to the same extent as the other parameters. The majority of occupants with MAIS 3+ injuries can be seen at a pulse duration between 80 ms and 160 ms. There are several occupant exposed to pulse durations above 150 ms that were uninjured.



Key

1 MAIS 3+

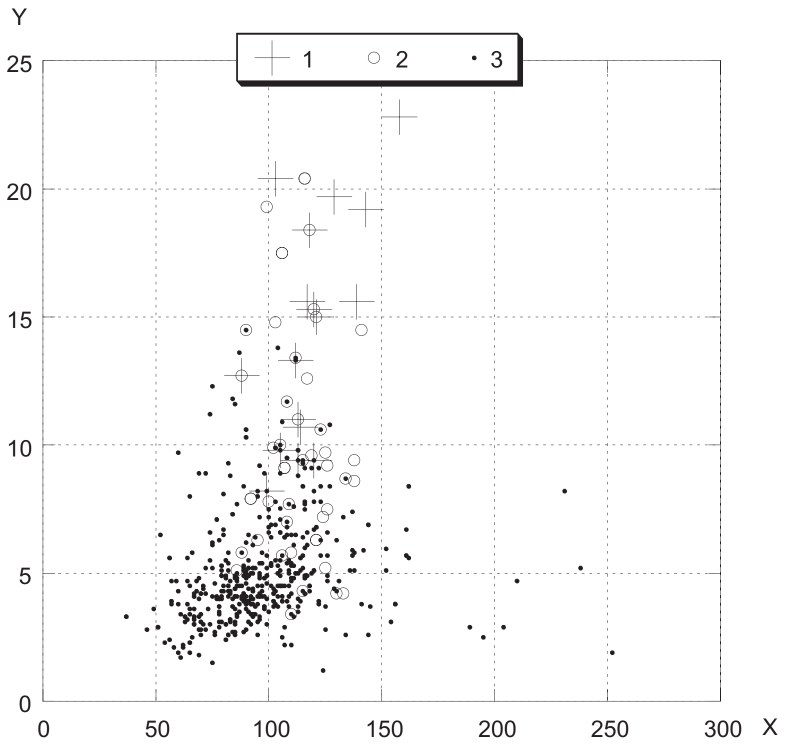
2 MAIS 2

3 MAIS 1 and uninjured

X peak acceleration [g]

Y mean acceleration [g]

Figure B.3 — Injury related to peak acceleration and mean acceleration



Key

1 MAIS 3+
2 MAIS 2
3 MAIS 1 and uninjured
X duration [ms]
Y mean acceleration [g]

Figure B.4 — Injury related to mean acceleration and duration

Annex C
(informative)

Misuse, limitations and traps

C.1 Human-related and vehicle-related parameters

Crash severity is only one of many parameters influencing the injury outcome in an accident. Other important **human-related parameters** include: physical fitness, age, gender, body size, body mass, occupant kinematics, and prior medical situation.

In addition to these human-related parameters, there are **vehicle-related parameters** that can influence injury outcome, including: intrusion of objects from outside the vehicle, unconstrained objects inside the vehicle, occupant contact outside the vehicle, occupant seating position, position of seat and steering-wheel, interior materials, seat belt use, seatbelt pre-tensioners and seatbelt force limiters, supplemental restraint system activation timing, or direction of impact forces. Although the crash signal is a parameter which may be used to describe impact severity, its direct correlation to injury outcome is uncertain due to the influence of the parameters identified above.

C.2 Limitations related to crash configurations

On the basis of this Technical Report, it is important to understand that there are limitations associated with various crash configurations that need to be considered.

C.2.1 Crash configurations with minor risk of misinterpretation or misuse

In combination with other crash reconstruction data, recorded crash pulse data may be useful in the following exemplary scenarios.

C.2.1.1 Planar longitudinal collisions (frontal or rear)

In frontal crash scenarios which exhibit predominantly longitudinal Δv signals, it is reasonable to determine impact severity from the recorded crash signal. There is little risk of misinterpretation for cases in which the front of the vehicle exhibits continuously distributed loading, both laterally and vertically, across the vehicle’s frontal or rear structure. Examples of these cases include under-ride situations, e.g. a passenger car collides with the rear end of a truck.

C.2.1.2 Planar side collisions

In some side crash scenarios which exhibit predominantly lateral Δv signals, it may be reasonable to determine impact severity from the recorded crash signal. There is little risk of misinterpretation for cases in which the side of the vehicle exhibits continuously distributed loading, both laterally and vertically, with low intrusion across the vehicle’s side structure.

C.2.2 Crash configurations with major risk of misinterpretation or misuse

In contrast with the scenarios described above, there are many crash events in which recorded crash signals may yield inaccurate assessment of impact severity. For these cases, it is especially important to note that the inaccuracy is further compounded if the crash signal is used to assess injury severity. In the following exemplary scenarios, it is critical that crash pulse recorder data be compared with other crash reconstruction data to ensure that impact severity is correctly estimated.

C.2.2.1 Damage to crash pulse recorder mounting

Crash events in which the data recorder's mounting surface is damaged due to intrusion may yield crash signals that are not representative of the vehicle crash pulse. In such cases the orientation of the crash signals cannot be determined reliably. Additionally, the signals represent local signals at the deforming mounting surface rather than signals of the vehicle.

C.2.2.2 Lateral crash

In lateral crash events, it is noted that acceleration-based crash signals are not sufficient to fully characterize impact severity. Therefore, if lateral Δ*v* (or acceleration) alone is used to estimate impact severity, it is quite possible that the conclusions will be flawed. To illustrate, consider the following exemplary scenarios:

— The side of a vehicle is struck such that there is limited engagement with the vehicle's primary structure (i.e. sill or b-pillar). While the struck vehicle may experience significant intrusion which results in high impact severity for the near side occupant, it is quite likely that the overall Δ*v* (or acceleration) may be quite low.

— The same vehicle is struck such that there is significant interaction with the vehicle's primary side structure. In this case, the struck vehicle may experience much less overall intrusion which results in low impact severity. However, Δ*v* (or acceleration) would be much higher than in the previous scenario.

C.2.2.3 Oblique crash

In oblique crash configurations the vehicle can experience severe deformation that is distributed across one corner of the vehicle. This type of crash yields acceleration values in the longitudinal and lateral directions; the magnitude of each signal is dependent upon the specific crash configuration. Therefore, the time-series data from both axes are important in determining impact severity. Also note that, as the crash progresses, the vehicle may experience rotation about the vertical axis which can result in artificially higher signals depending upon the location of the crash pulse recorder relative to the axis of vehicle rotation.

C.2.2.4 Glance-off crash

In glance-off crashes the vehicle can be subjected to a low overlap condition with very little structural engagement and may experience severe localized deformation accompanied by relatively low acceleration values. An assessment of Δ*v* (or acceleration) alone may lead to a mischaracterization of impact severity. Also note that, as the crash progresses, the vehicle may experience rotation about the vertical axis which can result in artificially higher signals depending upon the location of the crash pulse recorder relative to the axis of vehicle rotation.

C.2.2.5 Vehicle yaw during crash

In crashes with vehicle rotation about the vertical axis, crash pulse recorder signals can easily be misinterpreted. The acceleration signal at the crash sensor depends on the distance from the sensor location to the centre of vehicle rotation (see Reference[7]). In crashes with vehicle rotation, the crash sensor may be located far from the vehicle's centre of rotation. In this case, the longitudinal and lateral acceleration at the vehicle's centre of gravity is markedly different from that measured by the crash pulse recorder due to rotational components at the sensor location. In some cases the Δ*v* (or acceleration) signals can be reengineered if a sufficient rotational acceleration-time record is available.

C.2.2.6 Vertical components during crash

In crashes with vertical components, crash pulse recorder longitudinal and lateral signals can easily be misinterpreted if the vertical component is not properly accounted for. It is noted that many vehicles are not configured to record vertical acceleration for the purpose of supplemental restraint system activation. In crashes with significant vertical components, assessment of the lateral and/or longitudinal signals may underestimate the impact severity.

C.2.2.7 Rollover crash

In rollover crashes, crash pulse recorder signals can easily be misinterpreted. In this type of crash, accelerations in the longitudinal and lateral directions are insufficient to fully characterize impact severity.

C.2.2.8 Multiple crash events

Crash pulse recorders are limited with regard to the volume of data that can be stored. Therefore, in accidents which include multiple impact events, the number of events that can be captured is limited. In the United States, federally regulated event data recorders (EDR) typically capture no more than two events. For accidents that involve more events than can be recorded, the overall accident severity cannot be reliably determined from the recorded crash signals. Therefore, in crashes with multiple events, crash pulse recorder signals can easily be misinterpreted.

C.2.2.9 Narrow-object crash

In crashes with narrow objects, crash pulse recorder signals can easily be misinterpreted. These types of crashes may be accompanied by high levels of intrusion and relatively low levels of acceleration. Therefore, acceleration-based measures are insufficient to fully characterize impact severity.

C.2.2.10 Intrusion from external objects

In crashes with intrusion in which external objects penetrate the occupant compartment, crash pulse recorder signals are not applicable to determine crash severity. As noted above, these types of crashes may be accompanied by high levels of intrusion and relatively low levels of acceleration.

C.3 Limitations and traps related to recorder and recorded data

The following issues need to be evaluated and addressed in the analysis of crash pulse recorder data.

C.3.1 Valid recording

In presenting these guidelines for the interpretation of recorded crash pulse severity, the authors presume that the investigator/researcher has already validated that the recording made is a complete recording and comes from the crash under investigation. Some older factory equipped event data recorders require vehicle 12 V power for one or more seconds after a crash to complete making a new recording after a crash. If power is lost at impact, no new recording may be completed and an old crash may still be stored in memory. It is the responsibility of the investigator/researcher to compare the crash pulse recorder data to the physical evidence and validate that the recording is from the crash under investigation. These guidelines are how to interpret a previously validated recording.

C.3.2 Accelerometer position in vehicle

C.3.2.1 If the accelerometer measuring the crash severity is not located on the centre or gravity of the vehicle, and/or the line of force applied is not directed through the event data recorder, and vehicle rotation occurs, it is possible that the recorder may capture a pulse at its location that is different than the pulse experienced along the line of force applied. For example, if a recorder is mounted under the passenger seat and frontal crash forces are offset to the driver side causing a severe counter-clockwise rotation at impact, the recorder may capture less than the full pulse experienced by the driver location.

C.3.2.2 If the mounting surface of the recorder is deformed or displaced during the crash, the X and Y accelerometers may no longer point in their original directions and the event data recorder may record less than the full pulse. Rear or lateral displacement of the crash pulse recorder could result in higher accelerations being measured.

C.3.3 Accelerometer clipping

If the crash pulse exceeds the capability of the measuring accelerometer, pulse may be clipped and under-reported. For example, an 80 g pulse measured by a 50 g accelerometer will be reported as a 50 g event. The resultant Δv calculated from the acceleration data will also be under-reported.

C.3.4 Time truncation

While most recorders begin recording at algorithm wake-up, some event data recorders with continuously running algorithms that centre recordings on the deployment may not have sufficient memory before the deployment to capture the beginning of the crash pulse. Similarly, some event data recorders do not record for sufficient duration to capture the end of the crash pulse, resulting in truncated data and therefore a possible misinterpretation of crash severity.

C.3.5 Long recording

Some data recorders may record some pre-crash braking prior to the start of the crash and post-crash skidding from point of impact towards point of rest. Caution should be taken in the determination of the start and end of the crash pulse.

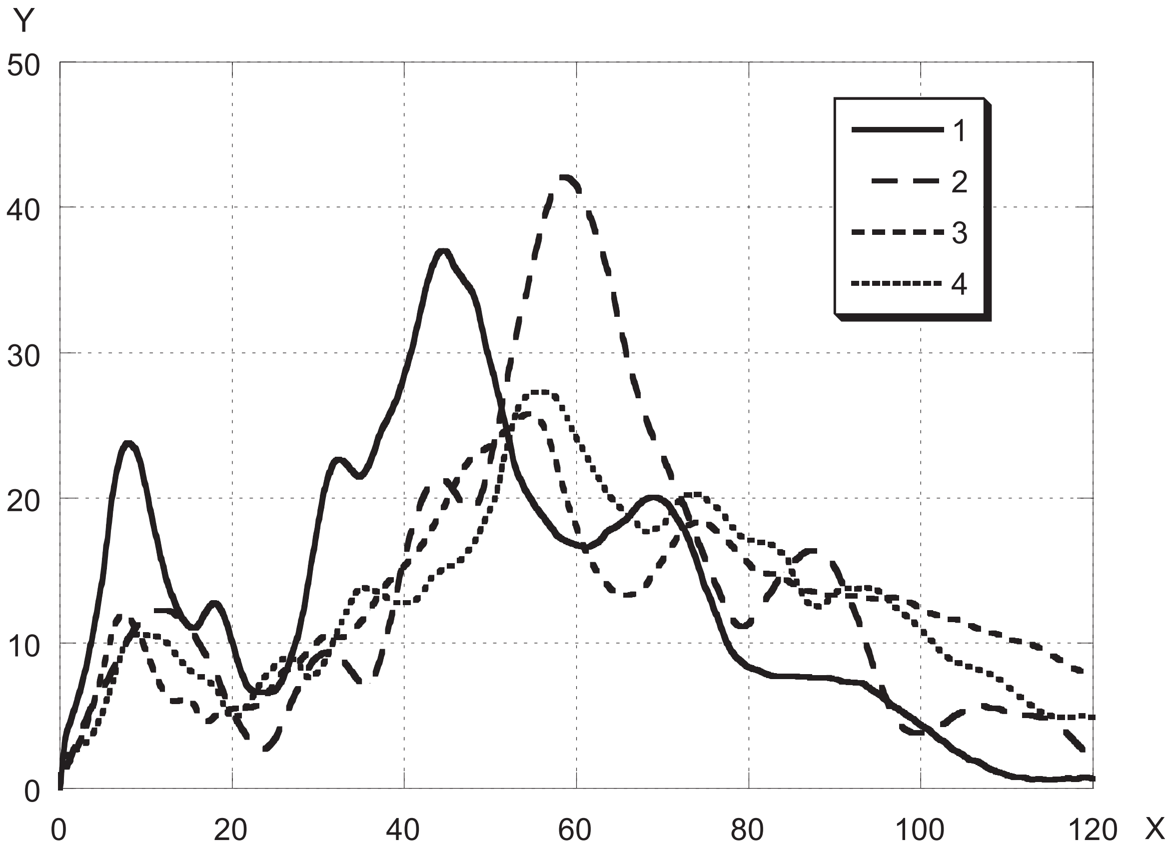
Annex D
(informative)

Examples of measured acceleration and analysis

D.1 Details for the crash pulses referred to in Clause 5

The conditions mentioned in Clause 5 are almost fulfilled for a series of four frontal impacts (see Figure D.1) with a different impact configuration but identical Δ*v* and EES values of 55 km/h each.

The individual crashes of the same vehicle model, conducted between 1987 and 1991, are shown in Figure D.1 below:



Key

1 impact against a rigid barrier with 100 % overlap at 55 km/h
2 impact against a rigid barrier with 50 % overlap at 55 km/h
3 impact against a rigid barrier with 40 % overlap at 55 km/h
4 car-to-car impact with 57 % overlap and a closing velocity of 110 km/h
X time [ms]
Y acceleration [g]

Figure D.1 — Crash pulses for different frontal impact configurations with the same Δ*v* and EES

Figure D.1 shows the different crash pulses for each test. Due to the fact that in combination with a belt pretensioner no significant interaction of the dummy's chest and the steering wheel could be observed in the high speed film analyses, the chest deceleration can be used as a parameter for that loading on the dummy which was mainly caused by the deceleration of the car itself. Taking the chest loading in the 100 % overlap test as 100 %, the following results can be provided for the chest deceleration for the different tests:

Test 1: 100 %

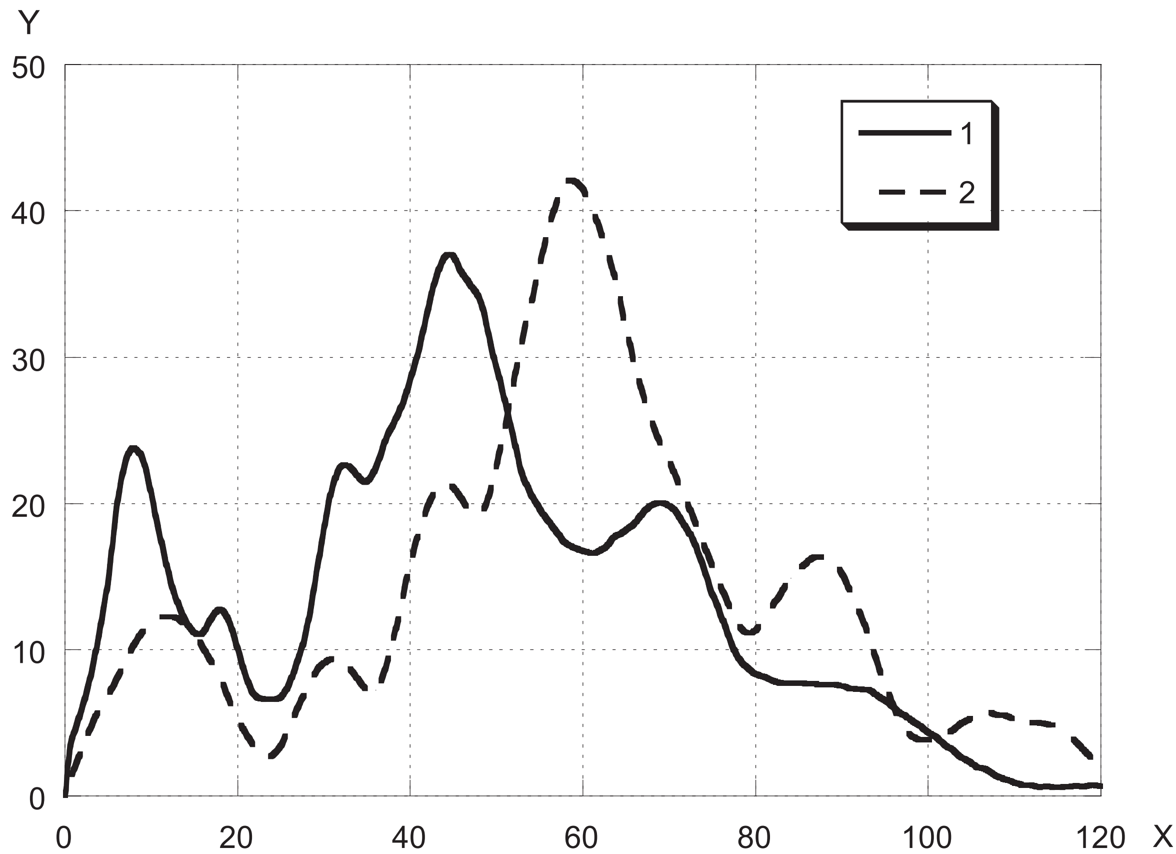
Test 2: 120 %

Test 3: 72 %

Test 4: 94 %

A comparison of the results shows three important aspects:

Comparison of Tests 1 and 2: The chest loading in an offset impact can be higher than in a full overlap impact.



Key

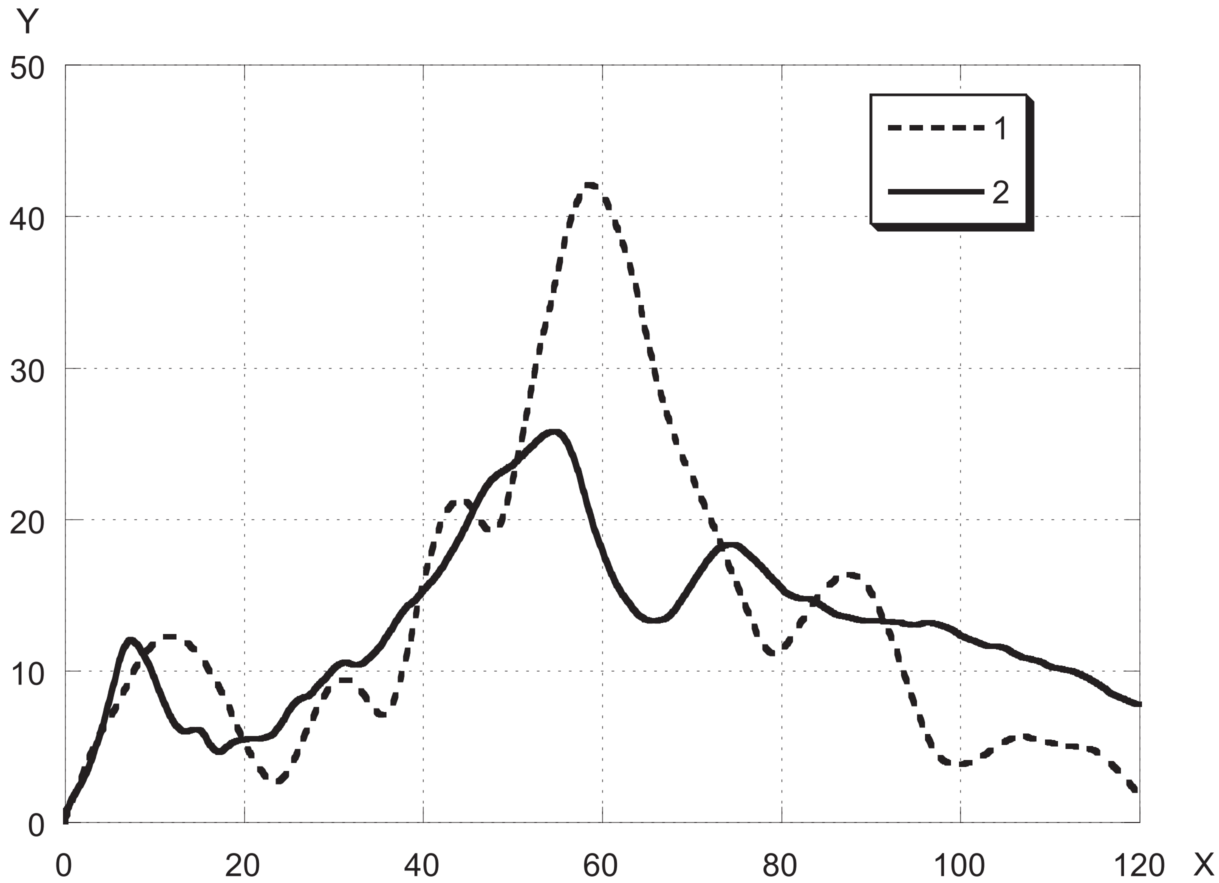
1 vehicle crash pulse in 100 % barrier test – chest loading 100 % at 74 ms

2 vehicle crash pulse in 50 % overlap barrier test – chest loading 120 % at 87 ms

X time [ms]

Y acceleration [g]

Figure D.2 — Crash pulse for 100 % barrier test compared with 50 % overlap barrier test



Key

1 vehicle crash pulse in 50 % overlap barrier test – chest loading 120 % at 87 ms

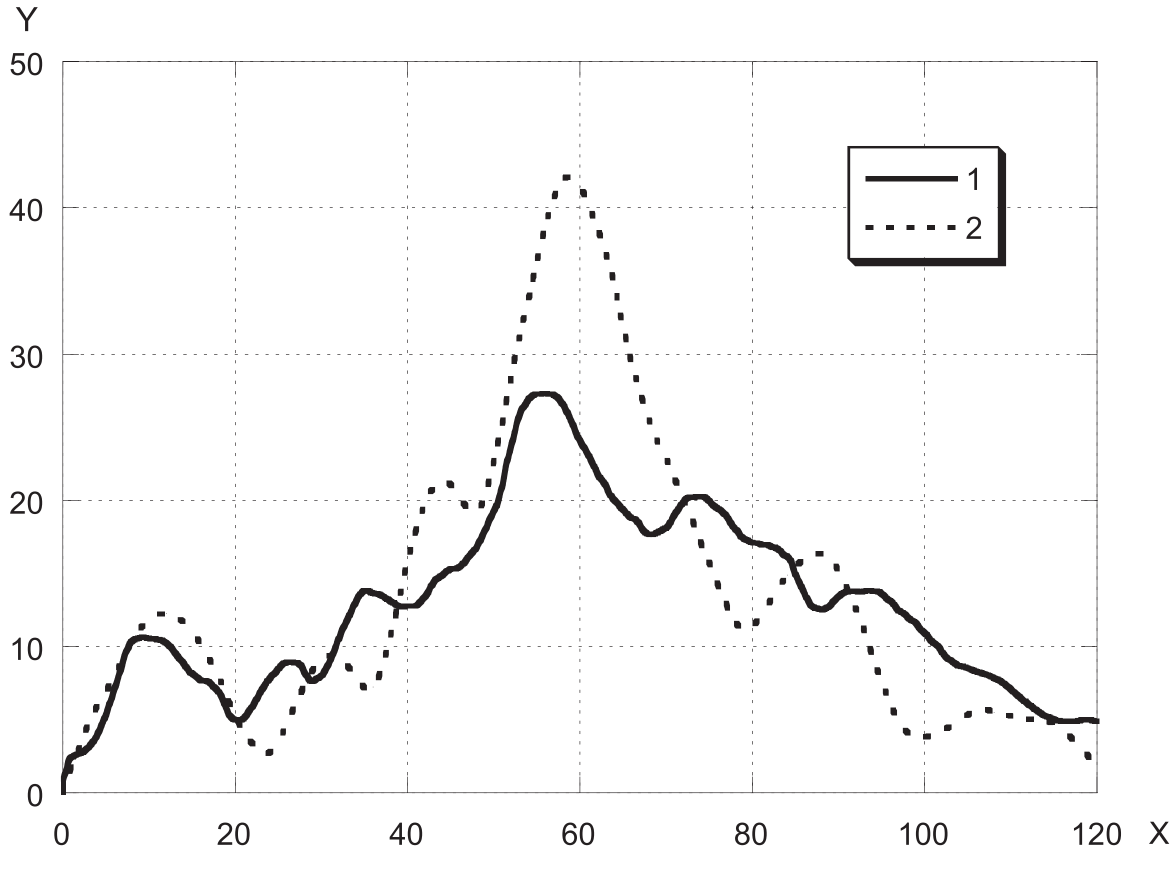
2 vehicle crash pulse in 40 % overlap barrier test – chest loading 72 % at 90 ms

X time [ms]

Y acceleration [g]

Figure D.3 — Crash pulse for 50 % overlap barrier test compared with 40 % overlap barrier test

Comparison of Tests 2 and 3: The difference in occupant loading with identical substitute parameters for impact severity can be so significant – even if the difference of the overlap degree is 10 % only – that the outcome might scatter between minor or very severe injuries. In the 50 % overlap test, the engine was involved in the crush, contributing to a higher peak.



Key

1 vehicle crash pulse in car-to-car impact with 57 % overlap and a closing velocity of 110 km/h – chest loading 94 % at 85 ms

2 vehicle crash pulse in 50 % overlap barrier test – chest loading 120 % at 87 ms

X time [ms]

Y acceleration [g]

Figure D.4 — Crash pulse for 50 % overlap barrier test compared with car-to-car impact test with 57 % overlap

Comparison of Tests 2 and 4: The car-to-car collision can result in different occupant loadings depending on the overlap degree and interaction of the structures and can therefore not be compared with the respective impact against a rigid object with an identical degree of overlap.

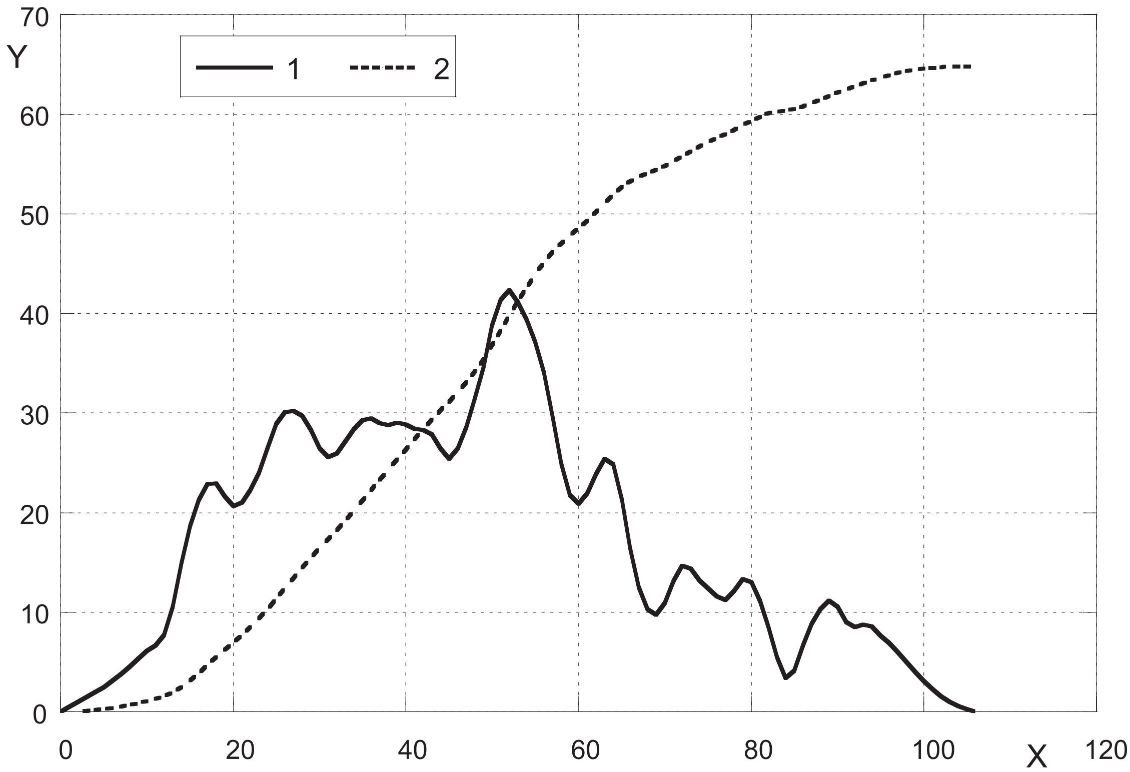
These significant differences can only be explained by the difference in the crash pulses, especially the magnitude and point of time of the maximum deceleration. These results prove the significance of knowing exactly the detailed crash pulse in order to evaluate impact severity.

Especially with respect to the activation of irreversible restraint systems such as airbags or belt pretensioners, detailed knowledge of the deceleration characteristic is urgently needed. The control units of these systems use an algorithm which takes the height, onset rate, and duration of the deceleration into account. Based on a first part of the deceleration characteristic, the decision is made to deploy or not to deploy an air bag. As the examples shown above clearly demonstrate, the risk for the occupants to be injured by deceleration-induced forces cannot be derived on the basis of a single substitute parameter for impact severity but have to consider a significant portion of the crash pulse itself.

D.2 Examples of single event crash pulse interpretation

The pulse in Figure D.5 is an example of the influence of time to peak acceleration in combination with the acceleration. High acceleration, 43 g, occurred at the time the occupants were completely in contact with the seat belt and possible maximum loading on the occupants. One of the two occupants sustained lumbar spine fractures.

The crash was a front-to-side impact into another vehicle with a full front into the B-pillar in a 90 degree angle. The change of velocity was 64 km/h. Considering the masses of the vehicles the impact velocity was estimated to approximately 100 km/h.



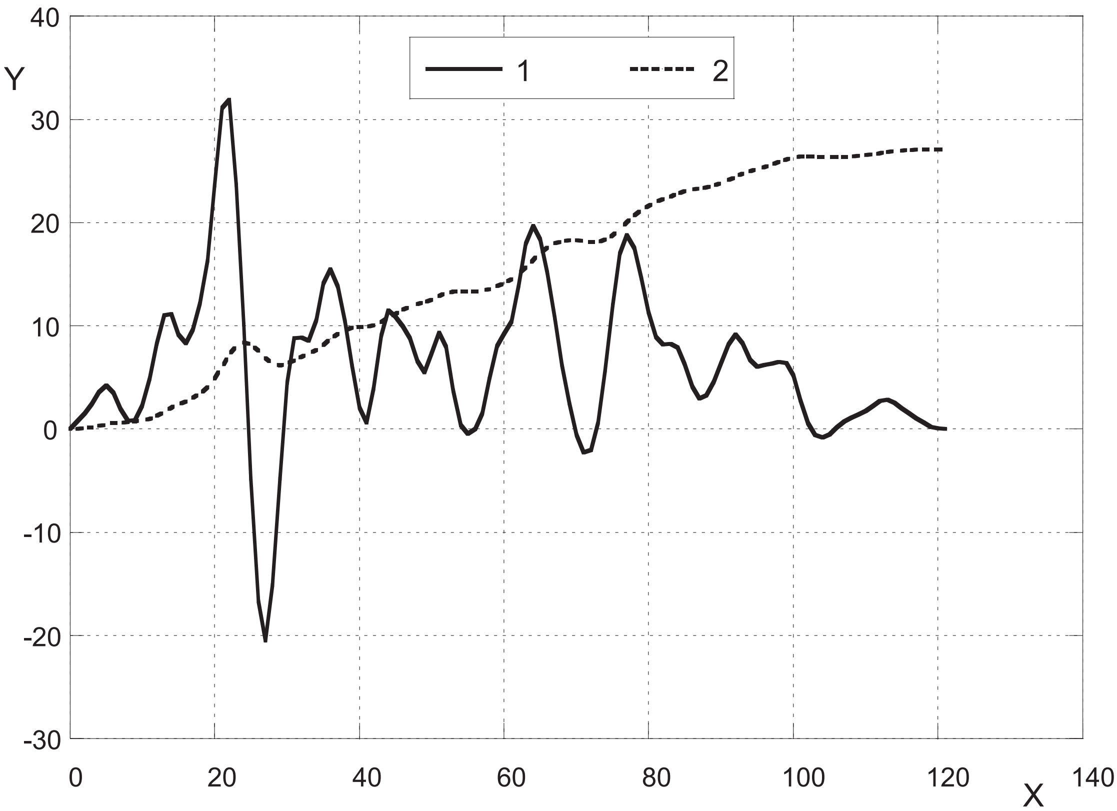
Key

1 acceleration-time history
2 Δv-time history
X time [ms]
Y acceleration [g], change of velocity [km/h]

Figure D.5 — Crash pulse Example 1

Figure D.6 shows an example of a small overlap crash. The pulse shape in this type of crash often consists of short peaks due to the fact that the structure of the car that is involved in the deformation is relatively weak between the stiff firewall, A-, B- and C-pillars.

The change of velocity may often be relatively low in small overlap crashes, while the vehicle deformation can be large due to the high kinetic energy in the crash. In this example the change of velocity was 28 km/h.



Key

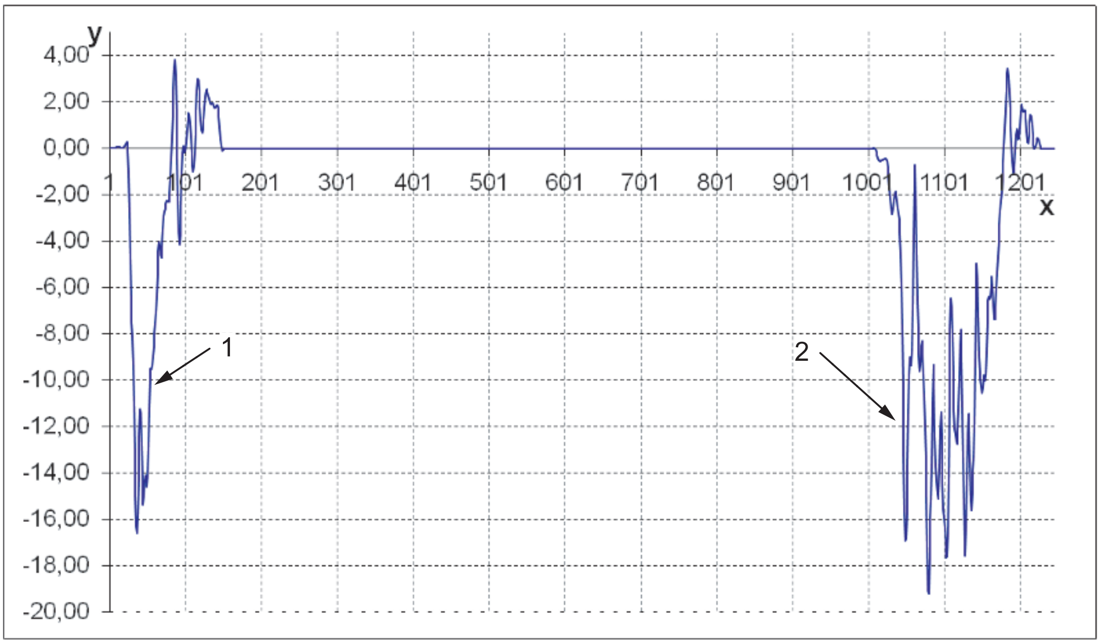
1 acceleration-time history
2 Δv-time history
X time [ms]
Y acceleration [g], change of velocity [km/h]

Figure D.6 — Crash pulse Example 2

D.3 Example of multiple event crash pulse interpretation

In the analysis of multiple impact crashes, especially when trying to link injury outcome to crash severity, it is important to have detailed knowledge about the crash severity (preferably the acceleration-time history) in each impact event as well as the time between the events. Restraint activation could occur in each event depending on the severity of each event and occupant kinematics. Variation in time and principal direction of force between the events, may affect whether the occupant is loaded to the restraint system or has a deviant position in second impact.

Figure D.7 shows the lateral pulses from a multiple side impact. In the first impact the case car was struck by a car in an intersection, skidded sideways and was struck the second time by a truck driving in the opposite direction. Time between the impacts was 850 ms (measured from end of the first impact to beginning of the second impact).



Key

1 first impact: Lateral mean acceleration of 7,0 g, Δ*v* of 16,7 km/h
2 second impact: Lateral mean acceleration of 9,2 g, Δ*v* of 51,4 km/h
X time [ms]
Y acceleration [g]

Figure D.7 — Multiple side impact, lateral acceleration pulse

This example illustrates that current analytic methods cannot generally accommodate multi-event collisions. That is, there is no simple means to combine multiple crash pulse measures into a single measure of crash severity. Instead, the analyst must review all available information for a multi-event crash, and consider the following:

a) Occupants, particularly unbelted occupants, may be out of normal seating position after the first event;

b) Frontal airbags and many side airbags may be designed to be effective for the duration of a single event, and may not provide an equivalent level of protection in subsequent events.

Annex E
(informative)

Calculation method for determination of t_0 and t_{end}, Methods A, B and C

E.1 General

Every real world accident is unique, in impact speed, acceleration shape, collision angle and overlap. To analyse an accident acceleration curve accurately, the following proposed modus operandi should establish a sound basis.

E.2 Definitions

t_0: Time where the left intersection line meets the zero line.

t_{end}: Time where the right intersection line meets the zero line.

$t_{(max)}$: Time where the acceleration during the crash reaches the maximum value.

$a_{(max)}$: Maximum peak of the filtered acceleration curve.

$a_{(90\ \%)}$: Acceleration value of 90 % of peak acceleration.

$t_{\mathbf{i}(90\ \%)}$: Time value at 90 % peak acceleration.

$a_{(10\ \%)}$: Acceleration value of 10 % of peak acceleration.

$t_{i(10\ \%)}$: Time value at 10 % peak acceleration.

g_i: Gradient between $a_{(90\ \%)}/t_{i(90\ \%)}$ and $a_{(10\ \%)}/t_{i(10\ \%)}$.

b_i: Centre of distance.

$a_{(accel/brake)}$: Average acceleration of speed up or brake acceleration before and / or after an incident.

Index i:

1 before/left side of acceleration curve of $a_{(max)}$

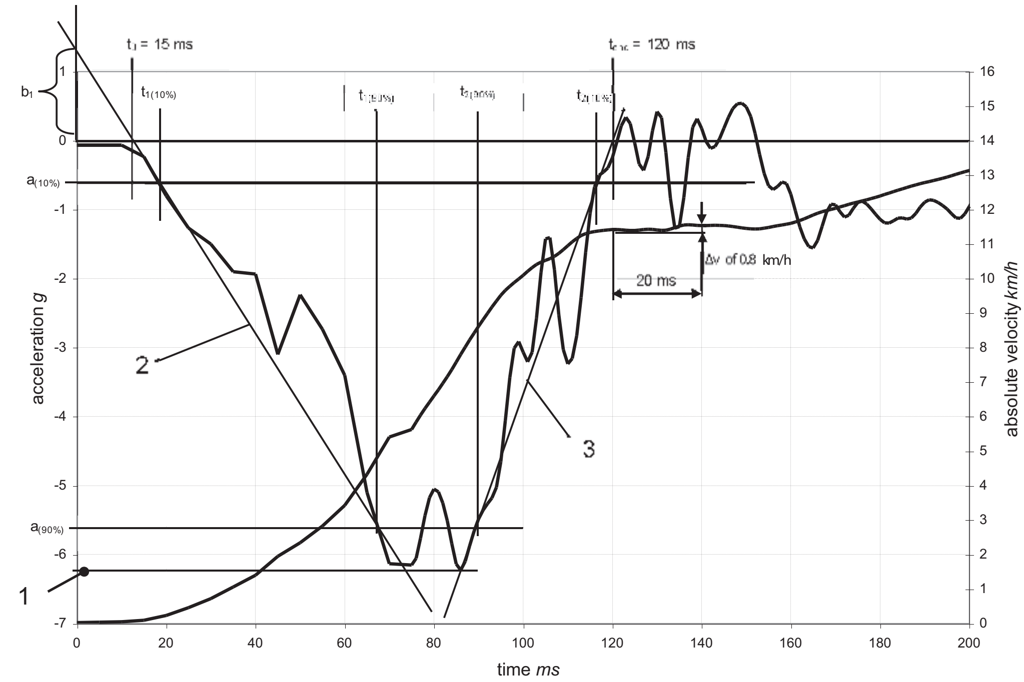
2 after/right side of acceleration curve of $a_{(max)}$

NOTE Influence of braking or acceleration during the crash sequence should be taken into account in the calculation of t_0 and t_{end}.

E.3 Calculation process

E.3.1 General

The next sections describe calculations according to Methods A, B (two versions) and C. The following chart shows an example of the calculation Methods A and B.



Key

1 peak acceleration

2 linear equation $f(t_1) = g_1 * t_1 + b_1$

3 linear equation $f(t_2) = g_2 * t_2 + b_2$

Figure E.1 — Longitudinal acceleration, frontal collision, ($v_{collision}$ = 22 km/h, 0 % overlap, 0° collision angle)

E.3.1.1 Accelerated or braked collision

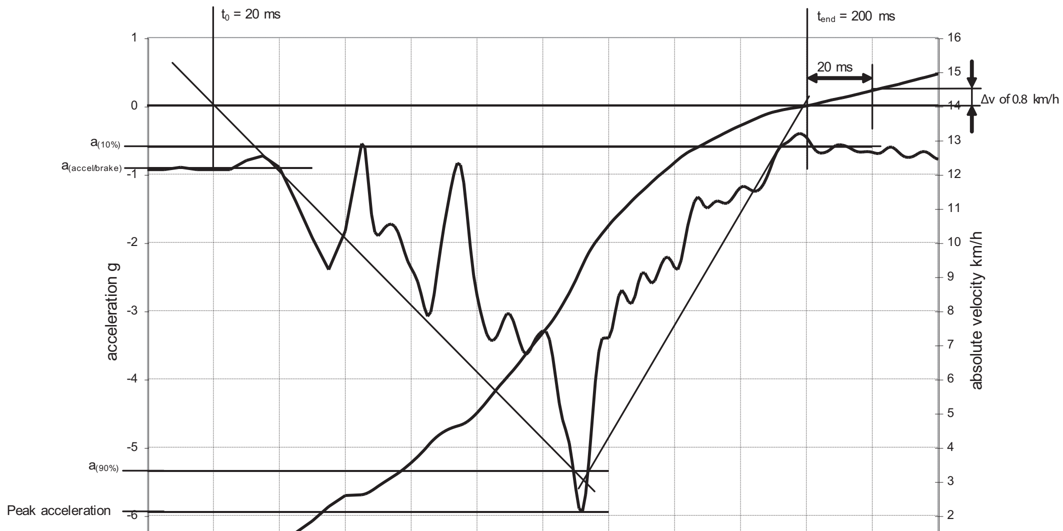


Figure E.2 — Longitudinal acceleration, frontal collision, accident with Crash Pulse Recorder

E.3.1.2 Lateral acceleration in frontal collision

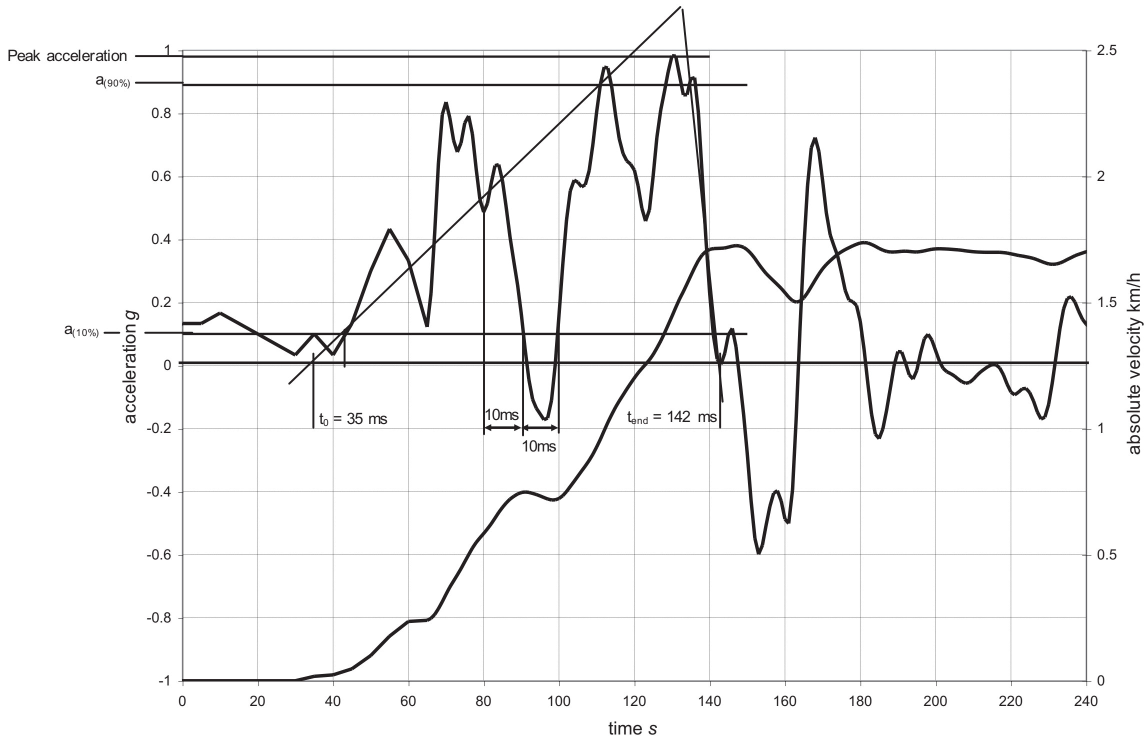


Figure E.3 — Lateral acceleration, frontal collision, accident with Crash Pulse Recorder

E.3.2 Method A

E.3.2.1 Calculation of t_0 and t_{end}

$$t_0 = \int_{t_0-20\text{ms}}^{t_0} a(t)\,\partial t = \Delta v \le 0.8\frac{km}{h}$$

$$t_{\text{end}} \int_{t_{\text{end}}}^{t_{\text{end}}+20\text{ms}} a(t)\,\partial t = \Delta v \le 0.8\frac{km}{h}$$

NOTE Δv = 0.8 km/h (ref. 5.2.3.1 and SAE J1698-1.

If we compare Method A with Method B the duration of Method A is always lower than the duration of Method B (mostly at low speed crashes). One reason is that we lose some milliseconds at t_0.

If we start with

$$t_0 = \int_{t0}^{t0+20\text{ms}} a(t)\,\partial t = \Delta v \ge 0.8\frac{km}{h}$$

we will get a better correlation.

E.3.3 Method B

E.3.3.1 Calculation of t_0 and t_{end}

To calculate t_0 use the left side of the maximum peak ($t_{(max)}$). For t_{end} use the right side of the maximum peak ($t_{(max)}$).

$$t_0 = \frac{b_{1(1,2)}}{g_1} \quad \text{(left side of } t_{(max)}\text{)}$$

$$t_{end} = \frac{b_{2(1,2)}}{g_2} \quad \text{(right side of } t_{(max)}\text{)}$$

where

$$g_i = \left(\frac{a_{(90\%)} - a_{(10\%)}}{t_{i(90\%)} - t_{i(10\%)}} \right)$$

$$b_{i1} = a_{(90\%)} - (g * t_{i(90\%)})$$

$$b_{i1} = a_{(10\%)} - (g * t_{i(10\%)})$$

E.3.3.2 Definition of $t_{i(90\,\%)}$

Definition for $t_{i(90\,\%)}$ if there are more than two t whereas $a(t) = a_{(90\,\%)}$:

$$t_{1(90\,\%)} := a(t_{1(90\,\%)}) = a_{90\,\%} \wedge a(t|\, t < t_{1(90\,\%)}) < a_{90\,\%}$$

$$t_{2(90\,\%)} := a(t_{2(90\,\%)}) = a_{90\,\%} \wedge a(t|\, t > t_{2(90\,\%)}) < a_{90\,\%}$$

E.3.3.3 Definition of $t_{i(10\,\%)}$

Definition for $t_{i(10\,\%)}$ if there are more than two t whereas $a(t) = a_{(10\,\%)}$:

Version 1: check the following acceleration if it is lower than $a_{(10\,\%)}$ in a timeframe of 10 ms

$$t_{1(10\,\%)} := a(t_{1(10\,\%)}) = a_{10\,\%} \wedge a(t|\, t_{1(10\,\%)\text{-10ms}} < t < t_{1(10\,\%)}) < a_{10\,\%}$$

$$t_{2(10\,\%)} := a(t_{2(10\,\%)}) = a_{10\,\%} \wedge a(t|t_{2(10\,\%)}) < t < t_{2(10\,\%)\text{+10ms}}) < a_{10\,\%}$$

If $a(t|\, t_{i(10\,\%\pm 10ms)} < t < t_{i(10\,\%)}) < a_{10\,\%}$ is false, check the following acceleration within 10 ms, if the following $a_{(t)} < a_{(10\,\%)}$, use the first determined value as $t_{i(10\,\%)}$.

Version 2: check the following acceleration if it is lower than $a_{(10\,\%)}$ in a timeframe of 20 ms

$$t_{1(10\,\%)} := a(t_{1(10\,\%)}) = a_{10\,\%} \wedge a(t|\, t_{1(10\,\%)\text{-20ms}} < t < t_{1(10\,\%)}) < a_{10\,\%}$$

$$t_{2(10\,\%)} := a(t_{2(10\,\%)}) = a_{10\,\%} \wedge a(t|t_{2(10\,\%)} < t < t_{2(10\,\%)\text{+20ms}}) < a_{10\,\%}$$

If $a(t|\, t_{i(10\,\%\pm 20ms)} < t < t_{i(10\,\%)}) < a_{10\,\%}$ is false, check the following acceleration within 20 ms, if the following $a_{(t)} < a_{(10\,\%)}$, use the first determined value as $t_{i(10\,\%)}$.

E.3.4 Method C

E.3.4.1 General

$t_{i(10\ \%)}$ and $t_{(max)}$ are determined as in Method B but from the 20 Hz filtered signal (SAE J211, CFC20). Time values $t_{1(10\ \%)}$ and $t_{2(10\ \%)}$ of the CFC20 filtered crash pulse are used for (equal to) t_0 and t_{end} of the CFC60 filtered crash pulse.

E.3.4.2 Calculation of t_0 and t_{end}

t_0 (CFC60 filtered crash pulse) = $t_{1(10\ \%)}$ (CFC20 filtered Crash pulse)

t_{end} (CFC60 filtered crash pulse) = $t_{2(10\ \%)}$ (CFC20 filtered Crash pulse)

To calculate $t_{1(10\ \%)}$ use the left side of the maximum peak ($t_{(max)}$). For $t_{2(10\ \%)}$ use the right side of the maximum peak ($t_{(max)}$) of the 20Hz filtered signal.

E.3.4.3 Definition for $t_{(max)}$

$$t_{(max)} := a(t_{(max)}) = a_{100\ \%} \wedge a(t|\ t < t_{(max)}) < a_{100\ \%} \wedge a(t|\ t > t_{(max)}) < a_{100\ \%}$$

E.3.4.4 Definition for $t_{i(10\ \%)}$ if there are more than two t whereas $a(t) = a_{(10\ \%)}$

Version 1: check the following acceleration if it is lower than $a_{(10\ \%)}$ in a timeframe of 10 ms

$$t_{1(10\ \%)} := a(t_{1(10\ \%)}) = a_{10\ \%} \wedge a(t|\ t_{1(10\ \%)\text{-}10ms} < t < t_{1(10\ \%)}) < a_{10\ \%}$$

$$t_{2(10\ \%)} := a(t_{2(10\ \%)}) = a_{10\ \%} \wedge a(t|t_{2(10\ \%)}) < t < t_{2(10\ \%)+10ms}) < a_{10\ \%}$$

If $a(t|\ t_{i(10\ \%\pm10ms)} < t < t_{i(10\ \%)}) < a_{10\ \%}$ is false, check the following acceleration within 10 ms, if the following $a_{(t)} < a_{(10\ \%)}$, use the first determined value as $t_{i(10\ \%)}$.

Version 2: check the following acceleration if it is lower than $a_{(10\ \%)}$ in a timeframe of 20 ms

$$t_{1(10\ \%)} := a(t_{1(10\ \%)}) = a_{10\ \%} \wedge a(t|\ t_{1(10\ \%)\text{-}20ms} < t < t_{1(10\ \%)}) < a_{10\ \%}$$

$$t_{2(10\ \%)} := a(t_{2(10\ \%)}) = a_{10\ \%} \wedge a(t|t_{2(10\ \%)} < t < t_{2(10\ \%)+20ms}) < a_{10\ \%}$$

If $a(t|\ t_{i(10\ \%\pm20ms)} < t < t_{i(10\ \%)}) < a_{10\ \%}$ is false, check the following acceleration within 20 ms, if the following $a_{(t)} < a_{(10\ \%)}$, use the first determined value as $t_{i(10\ \%)}$.

E.4 Conclusions and notes regarding the use of Methods A, B and C

The following conclusions were drawn:

— all methods show the same result if the speed change is in higher level (Δv > 20 km/h);

— in low speed change the methods show big differences in time and mean acceleration;

— one must pay attention if it was a braked collision and link to the analysis.

Method B should be an instruction to analyses of longitudinal and lateral acceleration curves. But for each axis special attention should be paid to the conditions. If the conditions do not fit, another analysis method should be chosen.

If the acceleration curve shows a speed up or braked acceleration (see Figure E.2) before and/or after the crash pulse and it is not possible to define $a_{(10\ \%)}$, draw one line representing $a_{(accel/brake)}$. Speed up or braking acceleration value should be calculated above a defined time frame. See Figure E.2. Experience: use for the representing $a_{(10\ \%)}$ value the full braking rate (full acceleration rate) before/after the crash.

At low acceleration and side impacts it may be possible, that the additional condition of Δv of 0,8 km/h is inapplicable. Therefore more attention has to be drawn to the other conditions.

Special attention has to be drawn to situations when there are multiple impacts or more than one crash pulse in a crash sequence.

Special attention has to be drawn when the course of the accident is a slipping or skidding accident.

For Version 1 and Version 2, the time scale of 10 ms and 20 ms should be chosen accurately for the analyses of an acceleration curve. The difference between Versions 1 and 2 is the time period before and after the peak in which the acceleration must not exceed the $a_{10\ \%}$ value. While method B is very sensible to short peaks (oscillations), Method A is difficult to apply for fully braked collisions.

Annex F
(informative)

Example pulses with calculated or measured characteristics according to the methods presented in this Technical Report

F.1 Presentation of example pulses and objectives of the comparison

The aim of Annex F is to apply all severity parameters discussed in this Technical Report to the same recorded data for comparison.

Examples 1 to 5 show parameters calculated from crashes where a high sample rate recorder captured data every millisecond. Methods A, B and C described in 5.2.3 were used on each of the five data sets to show how each calculates the beginning and end of the crash.

The objective is to show how methods A, B and C influence the calculation of severity measures, for example, to see if there were any systematic differences in the calculation of severity measures. Results with methods A, B and C including metrics such as t_0, t_{end}, Δv, average acceleration, peak acceleration and crash duration are tabulated below. ASI, VCD and VPI were also calculated for all pulses.

An additional objective was to compare the severity measures that can be calculated from EDR 10 ms Δv data to the 1 ms data, including the 10 ms rolling average acceleration described in A.3. The 1 ms data was processed as it would be by an airbag control module with an event data recorder calculating and storing Δv at 10 ms intervals. From that Δv, the average acceleration and peak acceleration values were calculated from the simulated EDR data as described in A.3.

Comparison graphs show how the peak CFC60 filtered data are not comparable to the EDR peak acceleration. The 10 ms rolling average, calculated from the high fidelity data, is more comparable to the peak acceleration data calculated from the EDR Δv.

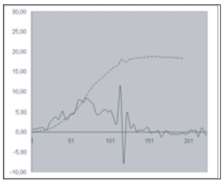
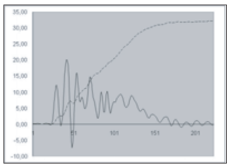
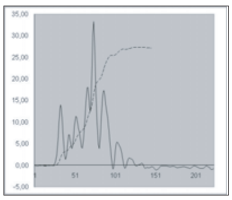
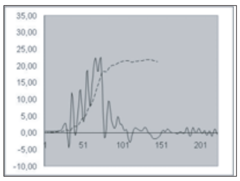
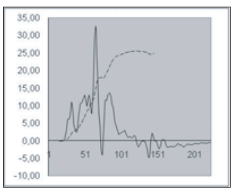
The methodology used to process the 1 ms data was to review the raw acceleration values and declare the first data point over 2 G's as the algorithm wake up or t_0. The end of the crash t_{end} was defined per the US 49 CFR Part 563 definition of a change of velocity of 0,8 km/h or less over a 20 ms time period for longitudinal pulses (5 ms for lateral pulses).

Summary data are tabulated below. Following the tabulation, a graph of the CFC60 filtered acceleration, the acceleration calculated from the EDR Δv, and the 10 ms rolling average acceleration from the CFC60 filtered data are displayed.

ASI, VCD and VPI were calculated on both the original acceleration pulse and on the surrogate acceleration pulse from the EDR Δv data.

For simplicity, only the X direction data has been plotted for Cases 1 to 4. Case 5 was a side impact and only the Y direction data has been plotted. See Table F.1.

Table F.1 — Comparison table, Cases 1 to 5

Illustration	Case	Method	t_0 ms	t_{end} ms	Dura-tion ms	Mean acc. g	Δ*v* km/h	VCD km/h	Peak acc. g	Peak 10 ms avg G g	ASI	VPI g
	1	A	24	133	109	4,5	18,4	17,8	11,6	8,0	0,5	17,2
		B	10	135	125	4,1	18,4					
		C	7	134	127	4	18,4					
		EDR Δ*v* only	22	151	129	4	17,9	17,1	8,0	8,0	0,5	17,3
	2	A	27	173	146	6	31,7	21,0	20,1	13,4	0,7	21,5
		B	24	167	143	6,2	31,5					
		C	19	168	149	5,9	31,6					
		EDR Δ*v* only	27	187	160	5,6	31,6	21,5	14,5	14,5	0,7	21,1
	3	A	30	125	95	8	27,2	25,4	33,2	21,5	1,0	30,1
		B	24	112	88	8,6	26,9					
		C	23	109	86	8,7	26,7					
		EDR Δ*v* only	28	128	100	7,7	27,2	25,4	20,3	20,3	0,8	29,4
	4	A	35	112	77	7,5	21,5	21,5	22,5	20,7	0,9	27,5
		B	21	101	80	7,3	21,3					
		C	32	100	68	8,3	21,2					
		EDR Δ*v* only	25	125	100	6	21,5	21,1	19,3	19,3	0,9	26,9
	5	A	28	94	66	9,9	23,8	-	32,7	20,3	1,2	-
		B	20	99	79	8,6	24,3					
		C	22	105	83	8,3	24,8					
		EDR Δ*v* only	25	105	80	8,7	25,3	-	14,1	14,1	1	-

NOTE VCD and VPI are primarily developed for longitudinal impacts and the values are thus not included for the side impact Case 5.

Reviewing the data above, note that Method A tends to declare the start of the pulse 8 ms to 9 ms later than Methods B and C, because it must wait until 0,8 km/h has been accumulated over 20 ms or less, but also identifies the end of the pulse as 4 ms to 5 ms later, resulting in the crash duration being reported as longer by 4 ms to 5 ms. This primarily affects the tails, so the "average G's" taken over the highest 50 ms are not affected. The Δ*v*'s are all relatively comparable.

The EDR end of the crash pulse can depend on when the algorithm is designed to go back to sleep. However, if Δ*v* is all that is available to determine the end of the crash, and the US 49 CFR Part 563 definition of < 0,8 km/h over 20 ms is used, the EDR data sets the end of the crash as 15 ms to 20 ms later than the other three methods. This results in a lower calculated average G's. See Table F.2.

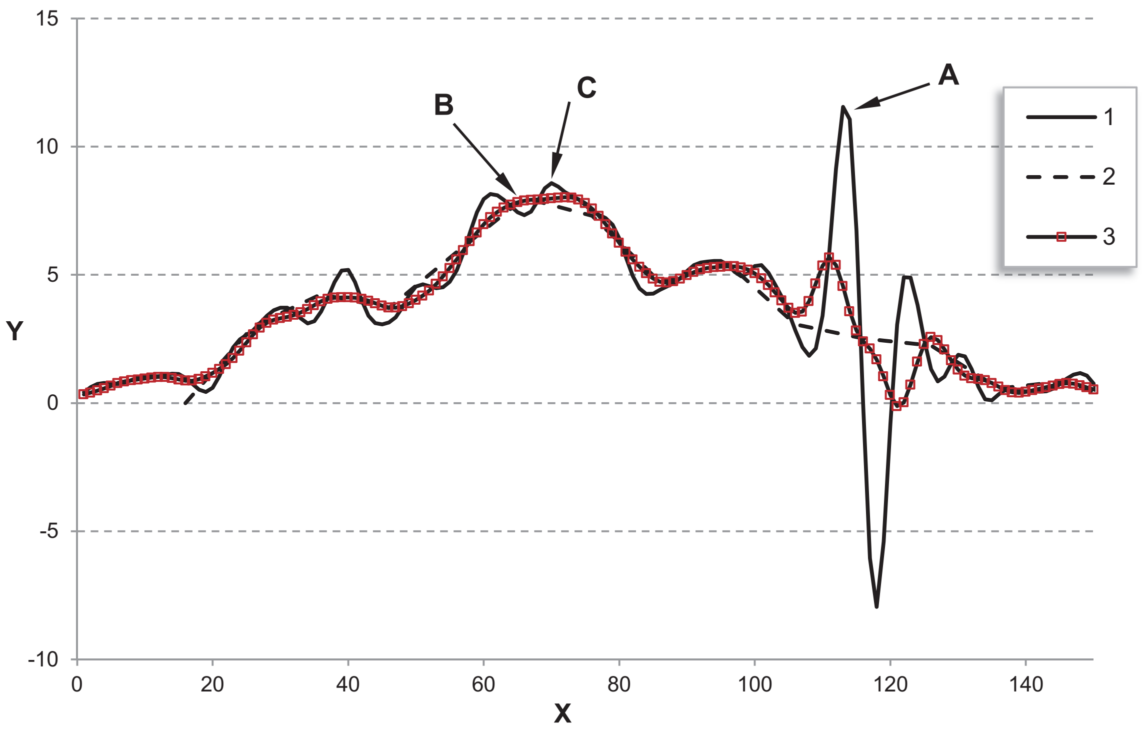
Table F.2 — Averages for the five cases in Table F.1 for the relevant parameters

	t_0	t_{end}	Duration	Mean acc.	Δv	Peak acc.	Peak 10 ms avg G
avg A	28,8	127,4	98,6	7,18	24,52	22,1	**16,8**
avg B	19,8	122,8	103,0	6,96	24,48		
avg C	20,6	123,2	102,6	7,04	24,54		
avg EDR	25,4	139,2	**113,8**	**6,40**	24,70	**15,2**	-

The 10 ms rolling average G's of 16,8 is 10 % higher than the EDR average G's of 15,2. Theoretically, the 10 ms rolling average peak should always be higher than the EDR surrogate acceleration peak 10 ms interval, because it always captures a local peak. The timing of the start and end of the interval for the 10 ms EDR reporting period will only perfectly capture the 1 ms data local peak one out of every ten times.

F.2 Application of 10 ms rolling average on the example pulses

Below follows a comparison of the acceleration pulses: Original 1 ms data, EDR data and application of 10 ms rolling average on the original pulse.



Key

1 acceleration-time history, 1 ms intervals

2 acceleration-time history, EDR representation with 10 ms intervals

3 acceleration-time history, 10 ms rolling average representation

A CFC60 peak G: 11,55 @ 113 ms (but a more realistic peak of 8,58 @ 70 ms)

B EDR peak G: 8,00 @ 66 ms

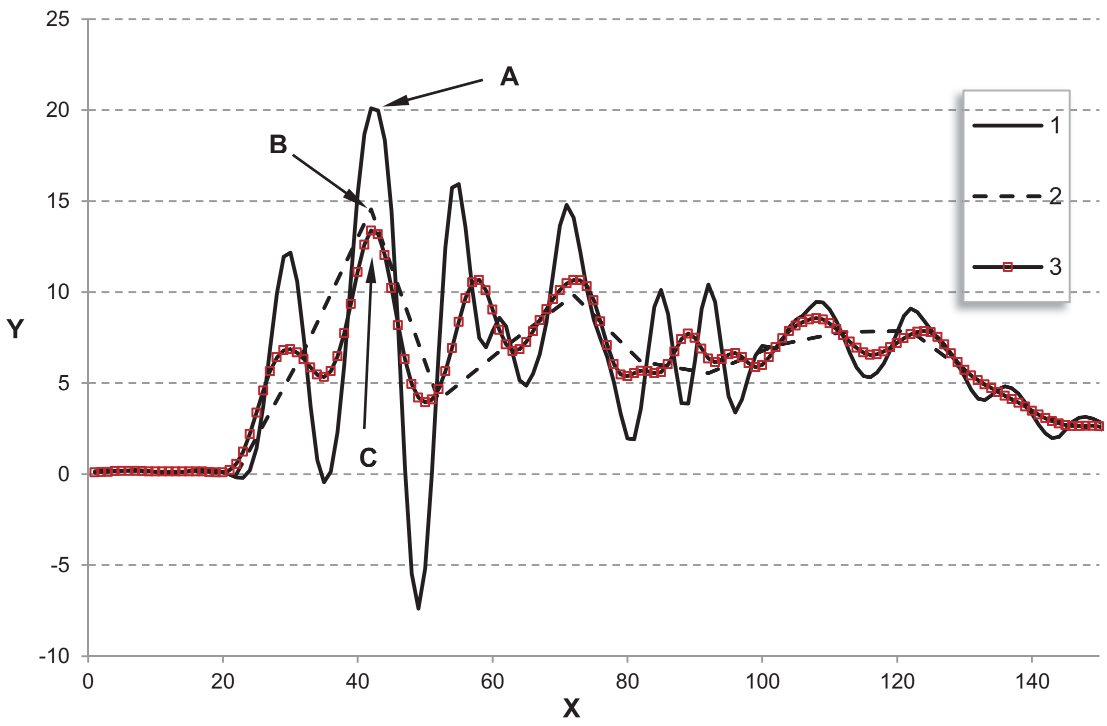
C 10 ms rolling average peak G: 8,03 @ 72 ms

X time [ms]

Y acceleration [g]

Figure F.1 — Case 1 analysis and application of 10 ms rolling average

Case 1 had an unusual spike near the end of the pulse such that the peak G's were not representative of the main portion of the crash. By taking the 10 ms rolling average of the acceleration, this peak was filtered out and the centre of the pulse became the dominant value, which is likely to correlate better to injury. The EDR calculated acceleration closely follows the 10 ms rolling average of the CFC60 filtered data, with a slight phase shift.



Key

1 acceleration-time history, 1 ms intervals

2 acceleration-time history, EDR representation with 10 ms intervals

3 acceleration-time history, 10 ms rolling average representation

A CFC60 peak G: 20,1 @ 42 ms

B EDR peak G: 14,55 @ 42 ms

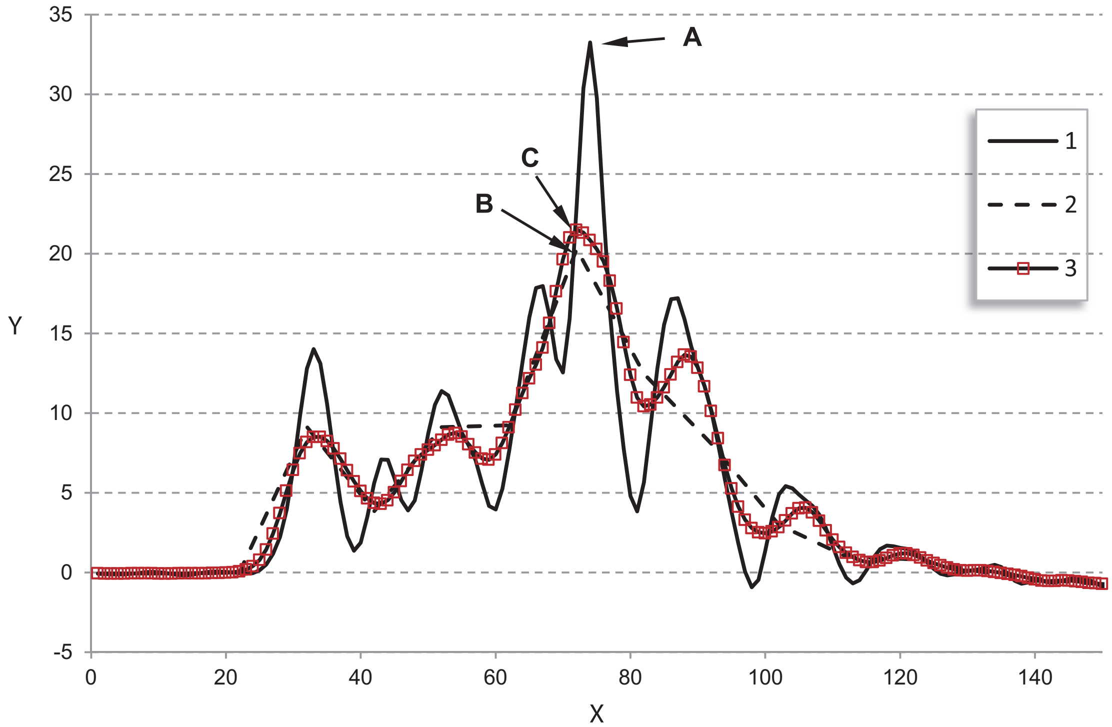
C 10 ms rolling average peak G: 13,38 @ 42 ms

X time [ms]

Y acceleration [g]

Figure F.2 — Case 2 analysis and application of 10 ms rolling average

Case 2 shows a severe oscillation in the CFC60 filtered data resulting in a 20 G peak acceleration. By coincidence the EDR 11-20 ms time period captures the peak, and because it is using the raw pulse data (not the CFC60 filtered) it actually reports a higher peak than the CFC60 10 ms rolling average (this is unusual – normally the 10 ms rolling average should be higher). The 10 ms rolling average is within 10 % of the EDR calculated acceleration peak value, with a slight phase shift.

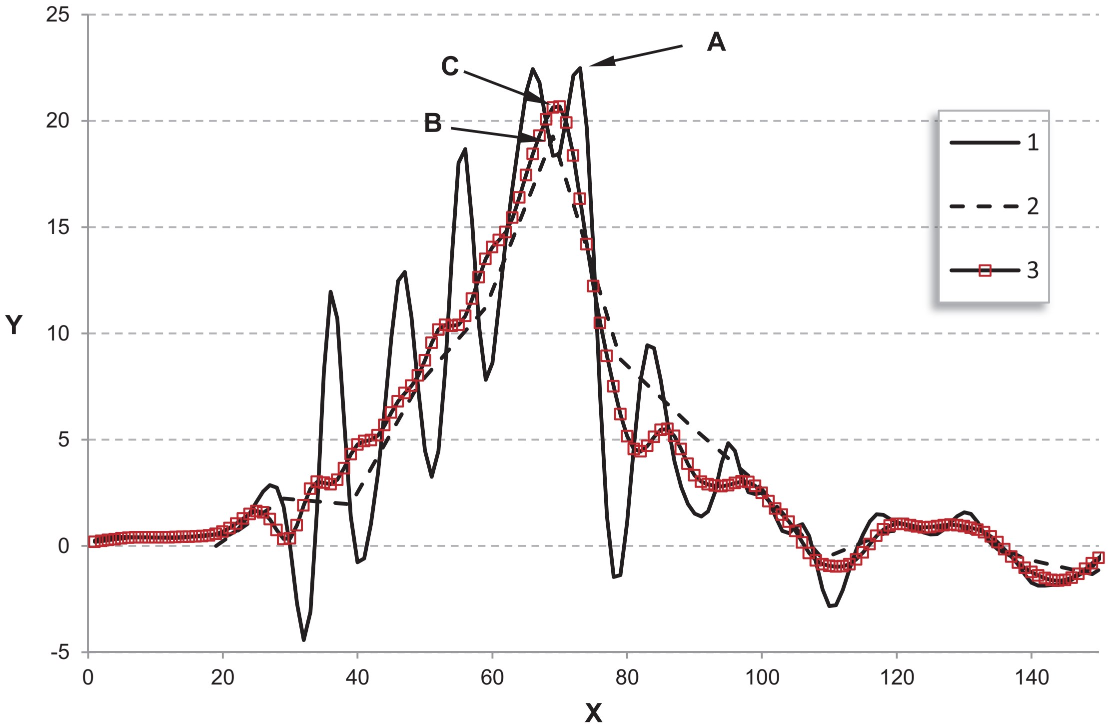


Key

1 acceleration-time history, 1 ms intervals
2 acceleration-time history, EDR representation with 10 ms intervals
3 acceleration-time history, 10 ms rolling average representation
A CFC60 peak G: 33,2 @ 74 ms
B EDR peak G: 20,3 @ 72 ms
C 10 ms rolling average peak G: 21,5 @ 72 ms
X time [ms]
Y acceleration [g]

Figure F.3 — Case 3 analysis and application of 10 ms rolling average

Case 3 shows the CFC60 filtered data still has oscillatory peaks such that the peak value for the vehicle may not represent the peak forces on the occupant well. The EDR calculated acceleration and the 10 ms rolling average give relatively comparable results.

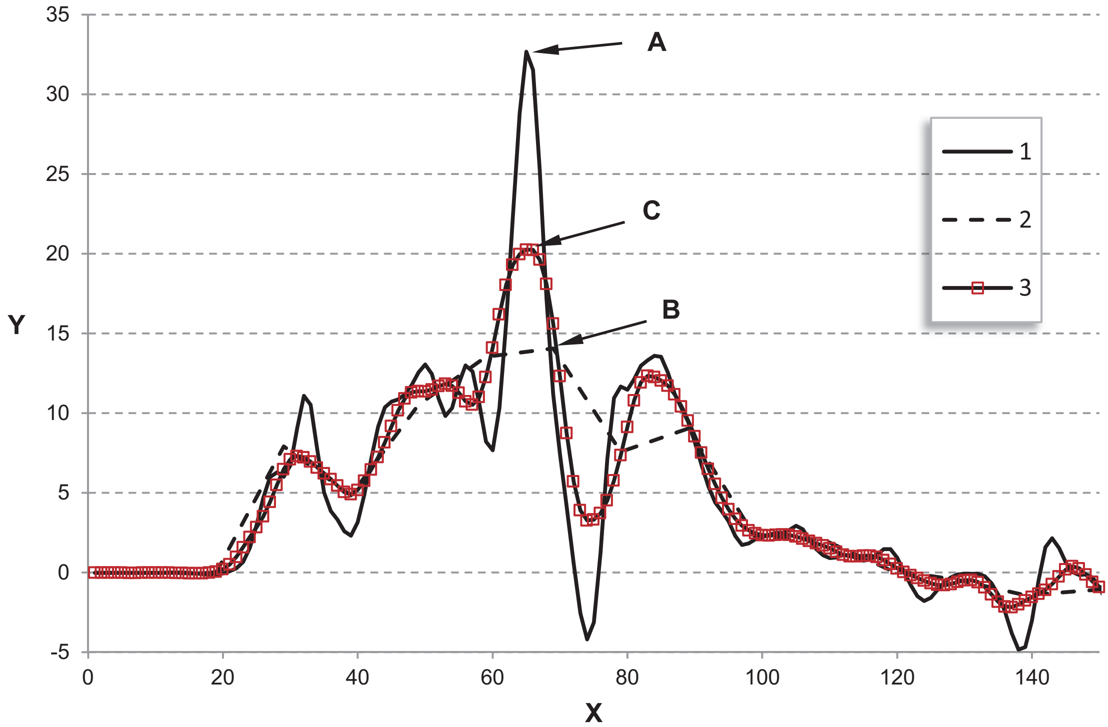


Key

1 acceleration-time history, 1 ms intervals
2 acceleration-time history, EDR representation with 10 ms intervals
3 acceleration-time history, 10 ms rolling average representation
A CFC60 peak G: 22,49 @ 73 ms
B EDR peak G: 19,26 @ 69 ms
C 10 ms rolling average peak G: 20,67 @ 70 ms
X time [ms]
Y acceleration [g]

Figure F.4 — Case 4 analysis and application of 10 ms rolling average

Case 4 produces relatively similar results for peak G's for CFC60 filtered, EDR, and 10 ms rolling average. This is the exception and not the rule. Note the slight phase shift in the EDR data. Since it only reports in 10 ms intervals it tends to lag the 10 ms rolling average data.



Key

1 acceleration-time history, 1 ms intervals
2 acceleration-time history, EDR representation with 10 ms intervals
3 acceleration-time history, 10 ms rolling average representation
A CFC60 peak G: 32,69 @ 65 ms
B EDR peak G: 14,05 @ 70 ms
C 10 ms rolling average peak G: 20,25 @ 65 ms
X time [ms]
Y acceleration [g]

Figure F.5 — Case 5 analysis and application of 10 ms rolling average

Case 5 is a side impact and only plots the y-axis data. The CFC60 data shows a sharp peak at 65 ms, due to the oscillation of even the 10 ms rolling average and the reporting interval of the EDR, the EDR ends up averaging the peak and valley near 70 ms and reports a substantially lower peak acceleration value. When there are sharp peaks, the beginning and end time of each EDR reporting interval can change how closely the peak acceleration from the EDR matches the 10 ms rolling average.

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