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## **EAST AFRICAN STANDARD**

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**Road restraint systems — Part 1: Terminology and general criteria  
for test methods**

**EAST AFRICAN COMMUNITY**

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## Foreword

Development of the East African Standards has been necessitated by the need for harmonizing requirements governing quality of products and services in East Africa. It is envisaged that through harmonized standardization, trade barriers which are encountered when goods and services are exchanged within the Community will be removed.

In order to meet the above objectives, the EAC Partner States have enacted an East African Standardization, Quality Assurance, Metrology and Test Act, 2006 (EAC SQMT Act, 2006) to make provisions for ensuring standardization, quality assurance, metrology and testing of products produced or originating in a third country and traded in the Community in order to facilitate industrial development and trade as well as helping to protect the health and safety of society and the environment in the Community.

East African Standards are formulated in accordance with the procedures established by the East African Standards Committee. The East African Standards Committee is established under the provisions of Article 4 of the EAC SQMT Act, 2006. The Committee is composed of representatives of the National Standards Bodies in Partner States, together with the representatives from the private sectors and consumer organizations. Draft East African Standards are circulated to stakeholders through the National Standards Bodies in the Partner States. The comments received are discussed and incorporated before finalization of standards, in accordance with the procedures of the Community.

Article 15(1) of the EAC SQMT Act, 2006 provides that "Within six months of the declaration of an East African Standard, the Partner States shall adopt, without deviation from the approved text of the standard, the East African Standard as a national standard and withdraw any existing national standard with similar scope and purpose".

East African Standards are subject to review, to keep pace with technological advances. Users of the East African Standards are therefore expected to ensure that they always have the latest versions of the standards they are implementing.

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## Introduction

In the preparation of this East African Standard, the following source was consulted extensively:

SANS 51317-1:2009, *Road restraint systems — Part 1: Terminology and general criteria for test methods*

Assistance derived from this source and others inadvertently not mentioned is hereby acknowledged.

Draft for comments only — Not to be cited as East African Standard

# Road restraint systems

## Part 1: Terminology and general criteria for test methods

The European Standard EN 1317-1:1998 has the status of a  
British Standard

ICS 01.040.13; 01.040.93; 13.200; 93.080.30

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# National foreword

This British Standard is the English language version of EN 1317-1:1998.

The UK participation in its preparation was entrusted by Technical Committee B/509, Road equipment, to Subcommittee B/509/1, Road restraint systems, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

This Part of BS EN 1317, together with Part 2 and the proposed Parts 3, 4 and 5, will collectively eventually supersede BS 6779 which will then be withdrawn. This is expected to take place by the end of 2000.

## Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

**Compliance with a British Standard does not of itself confer immunity from legal obligations.**

## Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 19 and a back cover.

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English version

## Road restraint systems — Part 1: Terminology and general criteria for test methods

Dispositifs de retenue routiers —  
Partie 1: Terminologie et dispositions générales pour  
les méthodes d'essais

Rückhaltesysteme an Straßen —  
Teil 1: Terminologie und allgemeine Kriterien für  
Prüfverfahren

This European Standard was approved by CEN on 5 March 1998.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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**CEN**

European Committee for Standardization  
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Ref. No. EN 1317-1:1998 E

## Foreword

This European Standard has been prepared by the Technical Committee CEN/TC 226, Road equipment, the Secretariat of which is held by AFNOR.

This European Standard consists of the following parts under the general title *Road restraint systems*.

Part 1: *Terminology and general criteria for test methods*;

Part 2: *Performance classes, impact test acceptance criteria and test methods for safety barriers*;

Part 3: *Crash cushions — Performance classes, impact test acceptance criteria and test methods for crash cushions*;

The following parts are not yet available but are in the course of preparation:

Part 4: *Impact tests acceptance criteria and test methods for terminals and transitions of safety barriers*;

Part 5: *Durability criteria and evaluation of conformity*;

Part 6: *Pedestrian road restraint system*.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by October 1998, and conflicting national standards shall be withdrawn at the latest by October 1998.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

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## Introduction

In order to improve and maintain highway safety, the design of safer roads requires the installation, on certain sections of road and at particular locations, of devices to restrain vehicles and pedestrians from entering dangerous zones or areas. The road restraint systems designated in this standard are designed to specified performance levels of containment, to redirect errant vehicles and to provide guidance for pedestrians or other road users.

The objective of this standard is to provide a procedure whereby the present national standards and regulations, which currently pertain in member countries, can be harmonized to a common European Standard.

Many types of road restraint systems are available; their characteristics differ both by function and by on-road use. European standardization requires common terminology in order to provide a clear understanding of the design, performance, production and construction of the various road restraint systems. This standard identifies impact test tolerances and vehicle behaviour criteria that need to be met to gain approval. The design specification, for road restraint systems entered in the test report, should identify the on-road site conditions under which the road restraint system should be installed.

The performance range of restraint systems, designated in this standard, enables national and local authorities to recognize and specify the performance class to be deployed.

The range of possible vehicular impact into an on-road road restraint system is extremely large in terms of speed, approach angle, vehicle type, vehicle performance, and other vehicle and road conditions. Consequently the actual on-road impacts which occur may vary considerably from the specific standard test conditions. However, adequate implementation of the standard should identify the characteristics, in a candidate safety road restraint system, that are likely to achieve maximum safety and reject those features which are unacceptable.

It is recommended that this standard is reviewed within a period of five years, or following the completion of a proposed set of impact validation tests.

## 1 Scope

This European Standard gives the definitions of the principal terms used for road vehicle restraint systems and pedestrian restraint systems in other parts of this standard. It also specifies the general provisions for test methods.

Informative annexes B and C give information on impact kinetic energy and vehicle acceleration.

## 2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 1317-2, *Road restraint systems — Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers.*

prEN 1317-3, *Road restraint systems — Part 3: Performance classes, impact test acceptance criteria and test methods for crash cushions.*

## 3 Abbreviations

ASI:	Acceleration severity index
THIV:	Theoretical head impact velocity
PHD:	Post-impact head deceleration
OIV:	Occupant impact velocity
ORA:	Occupant ridedown acceleration
VCDI:	Vehicle cockpit deformation index
VIDI:	Vehicle interior deformation index

## 4 Road restraint system terminology

The types of systems are shown in Figure 1.

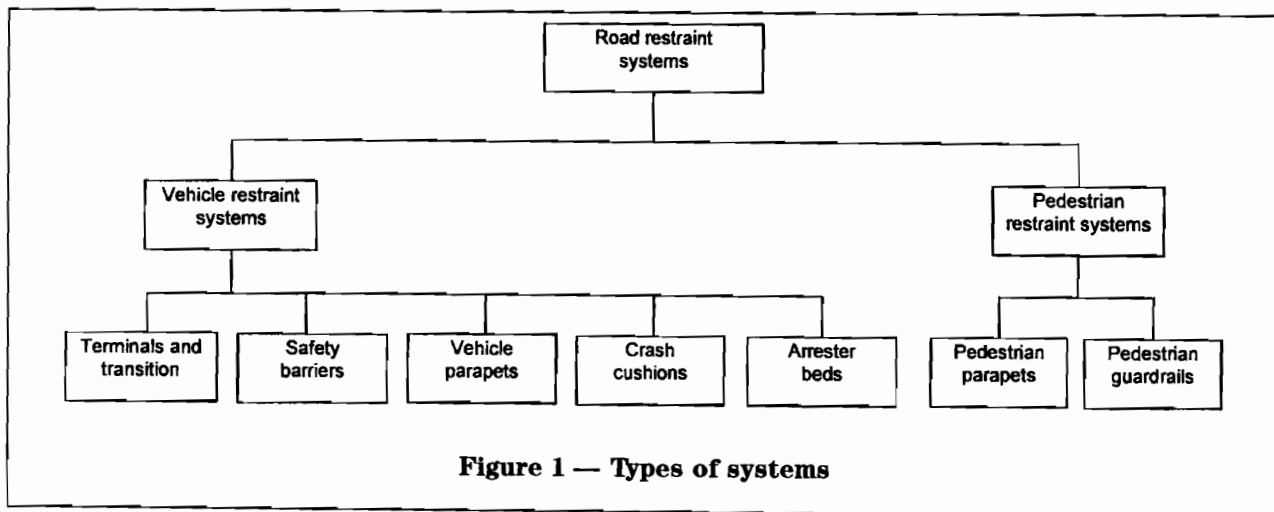


Figure 1 — Types of systems

For the purposes of this standard, the following definitions apply:

- 4.1 road restraint system**  
general name for vehicle restraint system and pedestrian restraint system used on the road
- 4.2 vehicle restraint system**  
system installed on the road to provide a level of containment for an errant vehicle
- 4.3 safety barrier**  
road vehicle restraint system installed alongside, or on the central reserve, of a road
- 4.4 permanent safety barrier**  
safety barrier installed permanently on the road
- 4.5 temporary safety barrier**  
safety barrier which is readily removable and used at road works, emergencies or similar situations
- 4.6 deformable safety barrier**  
safety barrier that deforms during a vehicle impact and may suffer permanent deformation
- 4.7 rigid safety barrier**  
safety barrier that has negligible deflection during a vehicle impact
- 4.8 single-sided safety barrier**  
safety barrier designed to be impacted on one side only
- 4.9 double-sided safety barrier**  
safety barrier designed to be impacted on both sides
- 4.10 terminal**  
the end treatment of a safety barrier
- 4.11 leading terminal**  
terminal placed at the upstream end of a safety barrier
- 4.12 trailing terminal**  
terminal placed at the downstream end of a safety barrier

- 4.13 transition**  
connection of two safety barriers of different designs and/or performances
- 4.14 vehicle parapet**  
safety barrier installed on the edge of a bridge or on a retaining wall or similar structure where there is a vertical drop, and which may include additional protection and restraint for pedestrians and other road users
- 4.15 crash cushion**  
road vehicle energy absorption device installed in front of a rigid object to reduce the severity of impact
- 4.16 redirective crash cushion**  
crash cushion designed to contain and redirect an impacting vehicle
- 4.17 non-redirective crash cushion**  
crash cushion designed to contain and capture an impacting vehicle
- 4.18 arrester bed**  
area of land adjacent to the road filled with a particular material to decelerate and arrest errant vehicles
- 4.19 pedestrian restraint system**  
system installed to restrain and to provide guidance for pedestrians
- 4.20 pedestrian parapet**  
pedestrian or "other users" restraint system along a bridge or on top of a retaining wall or similar structure which is not intended to act as a road vehicle restraint system
- 4.21 pedestrian guardrail**  
pedestrian or "other user" restraint system along the edge of a footway or footpath intended to restrain pedestrians and other users from stepping onto or crossing a road or other area likely to be hazardous  
NOTE. "Other users" includes provision for equestrians, cyclists and cattle.

## 5 Vehicle specifications under test conditions

Vehicle specifications under test conditions are specified in Table 1.

**Table 1 — Vehicle specifications**

<b>Mass</b>								
kg								
Vehicle mass (1)	825 ± 40	1 300 ± 65	1 500 ± 75	10 000 ± 300	13 000 ± 400	16 000 ± 500	30 000 ± 900	38 000 ± 1 100
Including maximum ballast (2)	100	160	180	—	—	—	—	—
Dummy	75	—	—	—	—	—	—	—
Total test mass	900 ± 40	1 300 ± 65	1 500 ± 75	10 000 ± 300	13 000 ± 400	16 000 ± 500	30 000 ± 900	38 000 ± 1 100
<b>Dimensions</b>								
m (limit deviation ±15%)								
Wheel track (front and rear)	1,35	1,40	1,50	2,00	2,00	2,00	2,00	2,00
Wheel radius (unloaded)	—	—	—	0,46	0,52	0,52	0,55	0,55
Wheel base (between extreme axles)	—	—	—	4,60	6,50	5,90	6,70	11,25
Number of axles	1S + 1 (3)	1S + 1	1S + 1	1S + 1	1S + 1	1S + 1/2	2S + 2	1S + 3/4
Ground clearance of the front bumper measured at the corner	—	—	—	0,58	—	0,58	0,58	0,58
<b>Centre of gravity location</b>								
m (limit deviation ±10 %)								
Longitudinal distance (4) from front axle (CGX) ±10 %	0,90	1,10	1,24	2,70	3,80	3,10	4,14	6,20
Lateral distance from vehicle centre line (CGY)	±0,07	±0,07	±0,08	±0,10	±0,10	±0,10	±0,10	±0,10
Height above ground (CGZ):								
Vehicle mass (±10 %)	0,49	0,53	0,53	—	—	—	—	—
Load (+15 % -5 %)	—	—	—	1,50	1,40	1,60	1,90	1,90
<b>Type of vehicle</b>	Car	Car	Car	Rigid HGV	Bus	Rigid HGV	Rigid	Articulated HGV
<p>(1) Including load for heavy goods vehicles (HGV).</p> <p>(2) Including measuring and recording equipment.</p> <p>(3) S: steering axle.</p> <p>(4) Vehicle mass.</p>								

## 6 Measurement of the acceleration severity index (ASI)

### 6.1 Calculation of ASI

The acceleration severity index ASI is a function of time, computed using the following equation (1):

$$ASI(t) = \left[ (\bar{a}_x/\hat{a}_x)^2 + (\bar{a}_y/\hat{a}_y)^2 + (\bar{a}_z/\hat{a}_z)^2 \right]^{1/2} \quad (1)$$

where:

$\hat{a}_x$ ,  $\hat{a}_y$  and  $\hat{a}_z$  are limit values for the components of the acceleration along the body axes  $x$ ,  $y$  and  $z$ ;  $\bar{a}_x$ ,  $\bar{a}_y$  and  $\bar{a}_z$  are the components of the acceleration of a selected point P of the vehicle, averaged over a moving time interval  $\delta = 50$  ms, so that:

$$\begin{aligned} \bar{a}_x &= \frac{1}{\delta} \int_t^{t+\delta} a_x dt; \\ \bar{a}_y &= \frac{1}{\delta} \int_t^{t+\delta} a_y dt; \\ \bar{a}_z &= \frac{1}{\delta} \int_t^{t+\delta} a_z dt. \end{aligned} \quad (2)$$

The index ASI is intended to give a measure of the severity of the vehicle motion for a person seated in the proximity of point P during an impact.

The average in equation (2) is actually a low pass filter, taking into account the fact that vehicle accelerations can be transmitted to the occupant body through relatively soft contacts, which cannot pass the highest frequencies.

Equation (1) is the simplest possible interaction equation of three variables  $x$ ,  $y$  and  $z$ . If any two components of vehicle acceleration are null, ASI reaches its limit value of 1 when the third component reaches its limit acceleration, but when two or three components are non-null, ASI may be 1 with the single components well below the relevant limits.

The limit accelerations are interpreted as the values below which passenger risk is very small (light injuries if any).

For passengers wearing safety belts, the generally used limit accelerations are:

$$\hat{a}_x = 12g, \hat{a}_y = 9g, \hat{a}_z = 10g \quad (3)$$

where:

$$g = 9,81 \text{ ms}^{-2} \text{ is the reference for the acceleration.}$$

With equation (1), ASI is a non-dimensional quantity and a scalar function of time, and, in general at the selected vehicle point, having only positive values. The more ASI exceeds unity, the more the risk for the occupant in that point exceeds the safety limits; therefore the maximum value attained by ASI in a collision is assumed as a single measure of the severity, or:

$$ASI = \max. [ASI(t)] \quad (4)$$

### 6.2 Vehicle instrumentation

Vehicle acceleration shall be measured at a single point (P) within the vehicle body close to the vehicle centre of gravity. Three acceleration transducers (or one tri-axial transducer) are then required.

Experience, however, shows that, due to physical constraints, the actual placement of the set of accelerometers may be offset several centimetres from the centre of gravity; then, significant differences can occur between measured accelerations and those at the centre of mass, due to angular motions. In these cases a second tri-axial transducer set of accelerometers shall be placed along the longitudinal axis.

In long vehicles acceleration can vary considerably from the front to the rear, mainly due to yaw motion. For example, in a bus colliding with a side barrier, it is recommended to evaluate ASI at two points (P<sub>1</sub> and P<sub>2</sub>), corresponding to the extreme forward and backward passenger positions: the most direct way to do this is to place two tri-axial transducers in such positions.

Alternatively, if a complete set of transducers is installed to record the six degrees of freedom motion of the vehicle, the complete vehicle acceleration field can be computed, and then the ASI index can be easily evaluated at any point.

The transducers, filters and recording channels shall comply with the frequency class specified in EN 1317-2 and prEN 1317-3.

### 6.3 Summary of the procedure to compute ASI

a) Record the measures of the three components of vehicle acceleration with the prescribed instrumentation. In general such measures are stored on a magnetic support, as three series of  $N$  numbers, sampled at a certain sampling rate  $S$  (samples per second).

For such three series of measures:

$$\begin{aligned} &^1a_x, ^2a_x, \dots, ^{k-1}a_x, ^ka_x, ^{k+1}a_x, \dots, ^Na_x \\ &^1a_y, ^2a_y, \dots, ^{k-1}a_y, ^ka_y, ^{k+1}a_y, \dots, ^Na_y \\ &^1a_z, \dots, ^{k-1}a_z, ^ka_z, ^{k+1}a_z, \dots, ^Na_z \end{aligned}$$

the acceleration of gravity  $g$  is the unit of measurement.

b) Find the number  $m$  of samples in the averaging window  $\delta = 0,05$  s:

$$m = \text{INT}(\delta \cdot S) = \text{INT}(0,05 \cdot S), \text{ where } \text{INT}(R) \text{ is the integer nearest to } R. \text{ For example, if } S = 500 \text{ samples/s, } m = 25.$$



c) Compute the average accelerations (2):

$${}^k\bar{a}_x = \frac{1}{m}$$

$$({}^k a_x + {}^{k+1} a_x + {}^{k+2} a_x + \dots + {}^{k+m} a_x) = \frac{1}{m} \sum_{j=k}^{k+m} j a_x \quad (5)$$

$${}^k\bar{a}_y = \frac{1}{m}$$

$$({}^k a_y + {}^{k+1} a_y + {}^{k+2} a_y + \dots + {}^{k+m} a_y) = \frac{1}{m} \sum_{j=k}^{k+m} j a_y \quad (6)$$

$${}^k\bar{a}_z = \frac{1}{m}$$

$$({}^k a_z + {}^{k+1} a_z + {}^{k+2} a_z + \dots + {}^{k+m} a_z) = \frac{1}{m} \sum_{j=k}^{k+m} j a_z \quad (7)$$

d) Compute ASI as a function of time (1):

$${}^k\text{ASI} = \left[ ({}^k\bar{a}_x/12)^2 + ({}^k\bar{a}_y/9)^2 + ({}^k\bar{a}_z/10)^2 \right]^{1/2} \quad (8)$$

e) Find ASI as the maximum of the series of  ${}^k\text{ASI}$ .

## 7 Measurement of the theoretical head impact velocity (THIV) and post-impact head deceleration (PHD)

### 7.1 General

The theoretical head impact velocity (THIV) concept has been developed for assessing occupant impact severity for vehicles involved in collisions with road vehicle restraint systems. The occupant is considered to be a freely moving object (head) that, as the vehicle changes its speed during contact with the vehicle restraint system, continues moving until it strikes a surface within the interior of the vehicle. The magnitude of the velocity of the theoretical head impact is considered to be a measure of the vehicle to vehicle restraint system impact severity.

The head is presumed to remain in contact with the surface during the remainder of the impact period. In so doing it experiences the same levels of acceleration as the vehicle during the remaining contact period (post-impact head deceleration — PHD).

## 7.2 Theoretical head impact velocity (THIV)

### 7.2.1 General

It can be assumed that at the beginning of the contact of the vehicle with the restraint system, both the vehicle and the theoretical head have the same horizontal velocity  $V_0$ , vehicle motion being purely translational.

During impact the vehicle is assumed to move only in a horizontal plane, because high levels of pitch, roll or vertical motion are not of prime importance unless the vehicle overturns. This extreme event does not need to be considered, as in this case the decision to reject the candidate system will be taken on the basis of visual observation or photographic recording.

Two reference frames are used, as indicated in Figure 2:

- a vehicle reference  $Cxy$ ,  $x$  being longitudinal and  $y$  transversal; the origin  $C$  is a point of the vehicle close to, but not necessarily coincident with the centre of gravity, where two accelerometers and a yaw rate sensor are installed. Let  $\ddot{x}_c$  and  $\ddot{y}_c$  be the accelerations of point  $C$  (in  $\text{m/s}^2$ ), respectively along the vehicle axis  $x$  and  $y$ , recorded from the two accelerometers, and  $\dot{\psi}$  the rate of yaw (in radians per second), recorded from the sensor ( $\dot{x}$  positive forward,  $\dot{y}$  positive to right-hand side and  $\dot{\psi}$  positive clockwise looking from above);

- a ground reference  $0XY$ , horizontal, with the  $X$  axis aligned with the velocity  $V_0$  and the origin  $0$  coinciding with the initial position of the vehicle datum point  $C$ .  $X_c(t)$ ,  $Y_c(t)$  are the ground co-ordinates of the vehicle reference  $C$ , while  $X_b(t)$ ,  $Y_b(t)$  are the ground co-ordinates of the theoretical head (see Figure 3).

With the definitions and the simplifying hypothesis of this paragraph, the vehicle and theoretical head motion shall be computed in accordance with 7.2.2 to 7.2.6.

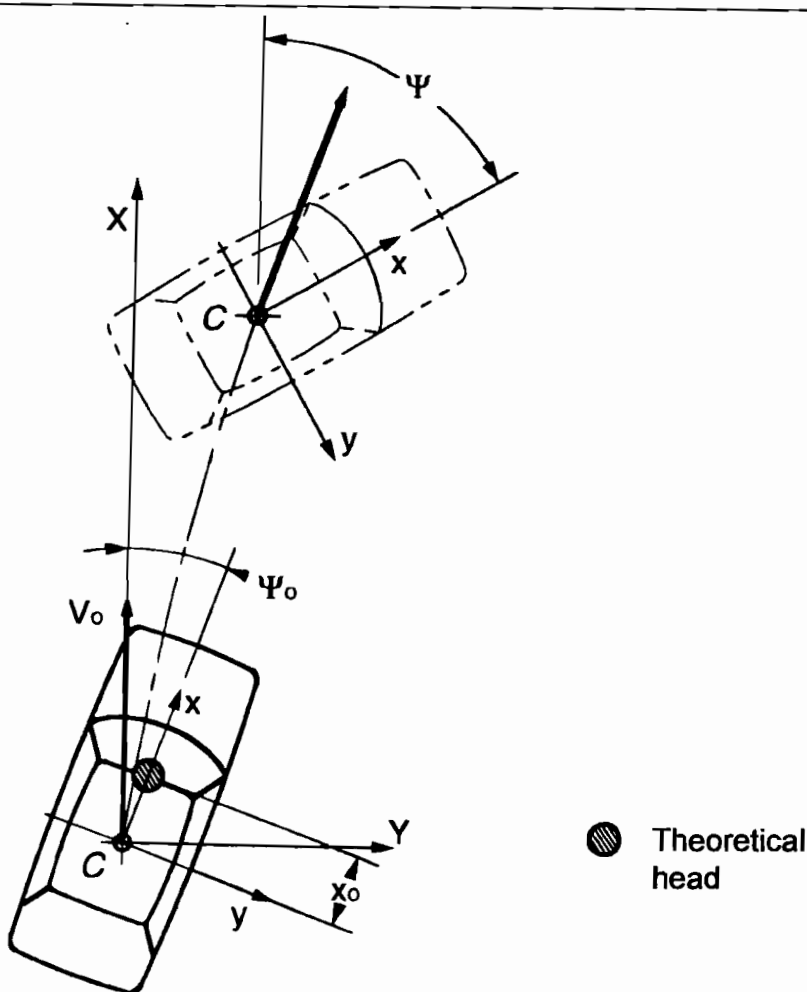


Figure 2 — Vehicle and ground reference frames

### 7.2.2 Vehicle motion

Initial conditions at time  $t = 0$ :

$$\begin{cases} X_c = 0 & Y_c = 0 & \psi = \psi_0 \\ \dot{X}_c = V_0 & \dot{Y}_c = 0 & \dot{\psi} = 0 \end{cases} \quad (9)$$

The yaw angle  $\psi$  shall be measured from the recording of a suitable overhead camera, or it shall be computed by integration of the yaw rate  $\dot{\psi}$  or other suitable means:

$$\psi(t) = \int_0^t \dot{\psi} dt + \psi_0 \quad (10)$$

then, from the components of vehicle acceleration in ground reference:

$$\begin{cases} \ddot{X}_c = \ddot{x}_c \cos \psi - \ddot{y}_c \sin \psi \\ \ddot{Y}_c = \ddot{x}_c \sin \psi + \ddot{y}_c \cos \psi \end{cases} \quad (11)$$

vehicle velocity and position are computed by integration:

$$\begin{cases} \dot{X}_c = \Delta \dot{X}_c + V_0 & \Delta \dot{X}_c = \int_0^t \ddot{X}_c dt \\ \dot{Y}_c = \Delta \dot{Y}_c & \Delta \dot{Y}_c = \int_0^t \ddot{Y}_c dt \end{cases} \quad (12)$$

$$\begin{cases} X_c = \int_0^t \Delta \dot{X}_c dt + V_0 t \\ Y_c = \int_0^t \Delta \dot{Y}_c dt \end{cases} \quad (13)$$



### 7.2.6 Value of THIV

Finally, the theoretical head impact velocity is the relative velocity at time  $T$ , i.e.:

$$\text{THIV} \left[ V_x^2(T) + V_y^2(T) \right]^{1/2} \quad (19)$$

THIV shall be reported in km/h.

### 7.3 Post-impact head deceleration

Post-impact head deceleration (PHD) is the maximum value of the resultant acceleration of point C, computed from the 10 ms average of the measured components  $\ddot{x}_c$  and  $\ddot{y}_c$ . If  $\langle \ddot{x}_c \rangle$  and  $\langle \ddot{y}_c \rangle$  are such components, then:

$$\text{PHD} = \text{MAX}(\langle \ddot{x}_c \rangle^2 + \langle \ddot{y}_c \rangle^2)^{1/2} \text{ for } t > T \quad (20)$$

PHD shall be reported in multiples of  $g^{(*)}$ .

### 7.4 Vehicle instrumentation

The vehicle should be fitted with one accelerometer for measurement in the longitudinal (forward) direction, one for the lateral (sideways) direction and, optionally, an angular velocity sensor (rate sensor). The three sensors should be mounted on a common block and placed at point C close to the vehicle centre of gravity.

The yaw angle shall be measured within a tolerance of  $\pm 4^\circ$ , directly from photographic records or by integration of yaw rate or by other means. The sampling interval shall not exceed 50 ms.

The transducers, filters and recording channels shall comply with the frequency class specified in EN 1317-2 and prEN 1317-3.

An event indicator is recommended to signal the moment of first vehicle contact with the vehicle restraint system.

### 7.5 Summary of the procedure to compute THIV and PHD

a) Record the vehicle accelerations and yaw rate, and store in digital form at the sample rate  $S$ ; let the data in the three record files be  ${}^k\ddot{x}_c$ ,  ${}^k\ddot{y}_c$  and  ${}^k\dot{\psi}$  ( $k = 1, 2, \dots, N$ ). The time interval between two subsequent data in the record file is  $h = t_k - t_{k-1} = 1/S$ . For example, if  $S = 500$  samples/s,  $h = 2$  ms.

b) Interpolate linearly between the measured values of the yaw angle to obtain the values  ${}^k\psi$ , or alternatively, integrate the yaw rate by the recurrent equation [from equation (2)]:

$$\begin{aligned} {}^1\psi &= \psi_0; \quad {}^2\psi = {}^1\psi + h \frac{{}^1\dot{\psi} + {}^2\dot{\psi}}{2}; \quad \dots; \\ {}^{k+1}\psi &= {}^k\psi + h \frac{{}^k\dot{\psi} + {}^{k+1}\dot{\psi}}{2} \end{aligned} \quad (21)$$

c) Compute the vehicle acceleration in ground reference (3):

$$\begin{aligned} {}^k\ddot{X}_c &= {}^k\ddot{x}_c \cos {}^k\psi - {}^k\ddot{y}_c \sin {}^k\psi \\ {}^k\ddot{Y}_c &= {}^k\ddot{x}_c \sin {}^k\psi + {}^k\ddot{y}_c \cos {}^k\psi \end{aligned} \quad (22)$$

d) Integrate the vehicle acceleration in ground reference equations (4), (9):

$$\begin{cases} {}^1\Delta\dot{X}_c = 0; & {}^{k+1}\Delta\dot{X}_c = {}^k\Delta\dot{X}_c + h \frac{{}^k\ddot{X}_c + {}^{k+1}\ddot{X}_c}{2} \\ {}^1\Delta\dot{Y}_c = 0; & {}^{k+1}\Delta\dot{Y}_c = {}^k\Delta\dot{Y}_c + h \frac{{}^k\ddot{Y}_c + {}^{k+1}\ddot{Y}_c}{2} \end{cases} \quad (23)$$

$$\begin{cases} {}^1\Delta X_b = X_0; & {}^{k+1}\Delta X_c = {}^k\Delta X_c - h \frac{{}^k\Delta\dot{X}_c + {}^{k+1}\Delta\dot{X}_c}{2} \\ {}^1\Delta Y_c = 0; & {}^{k+1}\Delta Y_c = {}^k\Delta Y_c - h \frac{{}^k\Delta\dot{Y}_c + {}^{k+1}\Delta\dot{Y}_c}{2} \end{cases} \quad (24)$$

e) Compute relative position and relative velocity of the theoretical head as functions of time, equations (8), (9):

$$\begin{cases} {}^kx_b(t) = {}^k\Delta X_b \cos {}^k\psi + {}^k\Delta Y_b \sin {}^k\psi \\ {}^ky_b(t) = -{}^k\Delta X_b \sin {}^k\psi + {}^k\Delta Y_b \cos {}^k\psi \end{cases} \quad (25)$$

$$\begin{cases} {}^kV_x = -{}^k\Delta\dot{X}_c \cos {}^k\psi - {}^k\Delta\dot{Y}_c \sin {}^k\psi + {}^kV_b \cos {}^k\psi \\ {}^kV_y = {}^k\Delta\dot{X}_c \sin {}^k\psi - {}^k\Delta\dot{Y}_c \cos {}^k\psi - {}^kV_b \sin {}^k\psi \end{cases} \quad (26)$$

f) Find the minimum value of  $j$  for which one of the three equations:

$${}^jx_b = D_x + X_0; \text{ or } {}^jy_b = D_y; \text{ or } {}^jy_b = -D_y \quad (27)$$

is satisfied.

g) Compute:

$$\text{THIV} = \left[ jV_x^2 + jV_y^2 \right]^{1/2} \quad (28)$$

h) Compute the 10 ms average  $\langle {}^k\ddot{x}_c \rangle$  and  $\langle {}^k\ddot{y}_c \rangle$ .

i) Compute the resultant vehicle acceleration ( ${}^kA$ ) in  $g$  as a function of time:

$${}^kA = \frac{1}{g} (\langle {}^k\ddot{x}_c \rangle^2 + \langle {}^k\ddot{y}_c \rangle^2)^{1/2} \quad (29)$$

### 7.6 Procedure for computing OIV and ORA

The above procedure can be simplified to compute the occupant impact velocity (OIV) and the occupant ridedown acceleration (ORA), by omitting step 2 and considering always  $\psi = 0$ .

### 8 Compensation for instrumentation displaced from the vehicle centre of gravity

Vehicular accelerations are used in the assessment of test results through ASI, THIV and the flail space model.

(\*)  $1g = 9,81 \text{ m}^{-2}$ .



This requires that a set of accelerometers should be placed at or close to the vehicle centre of mass. However, experience shows that this cannot always be done, due to physical constraints within the vehicle. As a result, actual placement of the set of accelerometers may be offset several centimetres from the centre of gravity, then, depending on the offset, significant differences can occur between measured accelerations and those at the centre of gravity, due to angular motions.

These differences can be minimized by the use of additional instrumentation. Therefore, in addition to the basic tri-axial set of accelerometers, it is recommended that a second tri-axial set be placed along the  $x$  (longitudinal) axis, as shown in Figure 2. With reference to Figure 4, for a point P located along the  $x$  axis at a distance  $x$  forward from the centre of gravity:

$$\begin{aligned} a_x &= a_{xc} - x(\omega_y^2 + \omega_z^2) \\ a_y &= a_{yc} - x\dot{\omega}_z \\ a_z &= a_{zc} - x\dot{\omega}_y \end{aligned} \quad (30)$$

where:

$a_x, a_y, a_z$  are the longitudinal, lateral and vertical accelerations of point P;

$a_{xc}, a_{yc}, a_{zc}$  are the longitudinal, lateral and vertical accelerations of the centre of gravity;

$\dot{\omega}_y, \dot{\omega}_z$  are the pitch and yaw rates;

$\omega_y, \omega_z$  are the pitch and yaw accelerations.

Thus, the accelerations of points P<sub>1</sub> and P<sub>2</sub> of Figure 4 are given by:

$$\begin{aligned} a_{x1} &= a_{xc} - x_1(\omega_y^2 + \omega_z^2) \\ a_{x2} &= a_{xc} - x_2(\omega_y^2 + \omega_z^2) \\ a_{y1} &= a_{yc} + x_1\dot{\omega}_z \\ a_{y2} &= a_{yc} + x_2\dot{\omega}_z \end{aligned} \quad (31)$$

$$a_{z1} = a_{zc} + x_1\dot{\omega}_y$$

$$a_{z2} = a_{zc} + x_2\dot{\omega}_y$$

From equation (2) the accelerations of the centre of gravity can be computed as follows:

$$a_{xc} = \frac{x_1 a_{x2} - x_2 a_{x1}}{x_1 - x_2}$$

$$a_{yc} = \frac{x_1 a_{y2} - x_2 a_{y1}}{x_1 - x_2}$$

$$a_{zc} = \frac{x_1 a_{z2} - x_2 a_{z1}}{x_1 - x_2}$$

(32)

## 9 Test report<sup>1)</sup>

The test report shall include the following information in the order given.

### a) Testing laboratory

Name

Address

Telephone number

Facsimile number

Test site location

### b) Report number

### c) Client

Name

Address

Telephone number

Facsimile number

### d) Test item

Received date

Tested date

Name of test item

Drawing enclosure No.

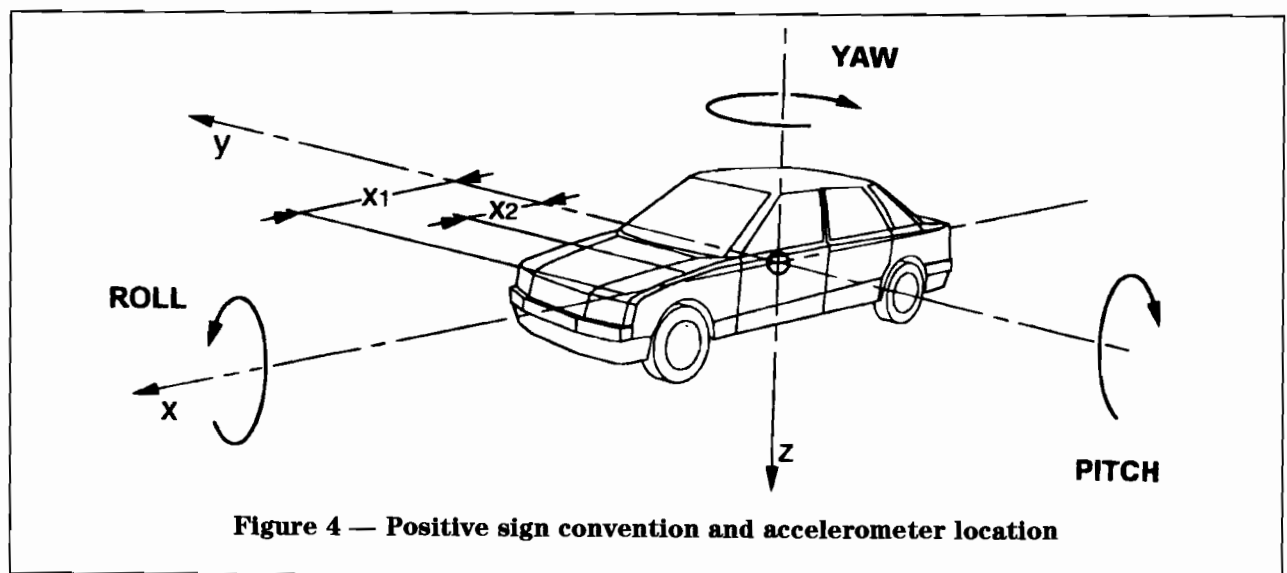


Figure 4 — Positive sign convention and accelerometer location

<sup>1)</sup> This proposal is based upon the criteria presented in paragraph 5.4.3 of the European Standard EN 45001:1998.

**e) Test procedure**

**1) Test type**

Target impact speed in kilometres per hour  
Target impact angle in degrees  
Target inertial vehicle test mass in kilograms

**2) Installation**

Detailed description of installation tested  
Test site drawing enclosure No., including end anchorages  
Photographs enclosure No.  
Length in metres  
A suitable description of the components of the vehicle restraint system for a guardrail consisting of post and beams:

- Beam rail member
- Beam rail length in metres
- Post material
- Post dimensions in metres
- Post embedment in metres
- Post spacing in metres

Soil type and condition

**3) Vehicle**

Model  
Model year  
Vehicle identification number (VIN)  
Vehicle mass in kilograms  
Ballast, position and mass  
Dummy (if fitted)  
Total test mass in kilograms  
Dimensions and characteristics of vehicle enclosure No.  
Position of centre of gravity  
Photographs enclosure

**f) Results**

Test No.  
Date  
Weather conditions at test  
General description of test sequence

**1) Test item**

Maximum dynamic deflection in metres  
Working width in metres  
Maximum permanent deflection in metres  
Length of contact in metres  
Impact point  
Major parts fractured or detached (Yes/No)  
Description of damage to test item

Ground fixing meets design levels (Yes/No/Not applicable)

Photographs of test item enclosure  
Drawing of test item enclosure  
\*) Barrier ground fixing force measurement in newtons  
\*) Force graphs enclosure

**2) Vehicle**

Impact speed in kilometres per hour  
% difference from target speed in per cent  
Impact angle in degrees  
% difference from target angle in degrees  
Within tolerance limits (Yes/No)  
\*) Exit speed in kilometres per hour  
\*) Exit angle in degrees  
\*) Rebound distance in metres  
Vehicle breaches barrier (Yes/No)  
Vehicle passes over the barrier (Yes/No)  
Vehicle within "box" (Yes/No)  
Vehicle rolls over within test area (Yes/No)  
General description of vehicle trajectory  
Vehicle cockpit deformation index VCDI (see annex A)

Major part of vehicle detached (Yes/No)  
Photographs of the vehicle enclosure No.

**3) Assessment of the impact severity**

Acceleration severity index, ASI  
Theoretical head impact velocity, THIV and post-impact head deceleration, PHD  
Flail space in metres  
Time of flight in milliseconds  
THIV in kilometres per hour  
PHD in *g*  
\*) Occupant impact velocity, OIV  
Forward in metres per second  
Lateral in metres per second  
Occupant ridedown acceleration  
Forward in *g*  
Lateral in *g*  
Acceleration graphs enclosure No.

**g) General statements**

The test results in this report relate only to the items tested.  
This report may not be reproduced other than in full, except with the prior written approval of the issuing laboratory.

**h) Approval of report**

Date  
Signature  
Title  
Name

\*) The asterisk indicates optional information.

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**Annex A (normative)**

**Vehicle cockpit deformation index (VCDI)**

**A.1 Deformation**

The vehicle cockpit deformation index (VCDI) comes from the vehicle interior deformation index (VIDI), which has been developed within the frame of different international meetings in 1970 and 1971.

This index designates both the location and the extent of the deformation of the cockpit. It consists of two alphabetic characters plus seven numeric characters, in the form:

*XXabcdefg*

The purpose of this index is to report a standard description of the deformation of vehicle interior, to help the understanding of the severity of the impact. The recommended accuracy in distance measurements is  $\pm 0,02$  m.

**A.2 Location of the deformation**

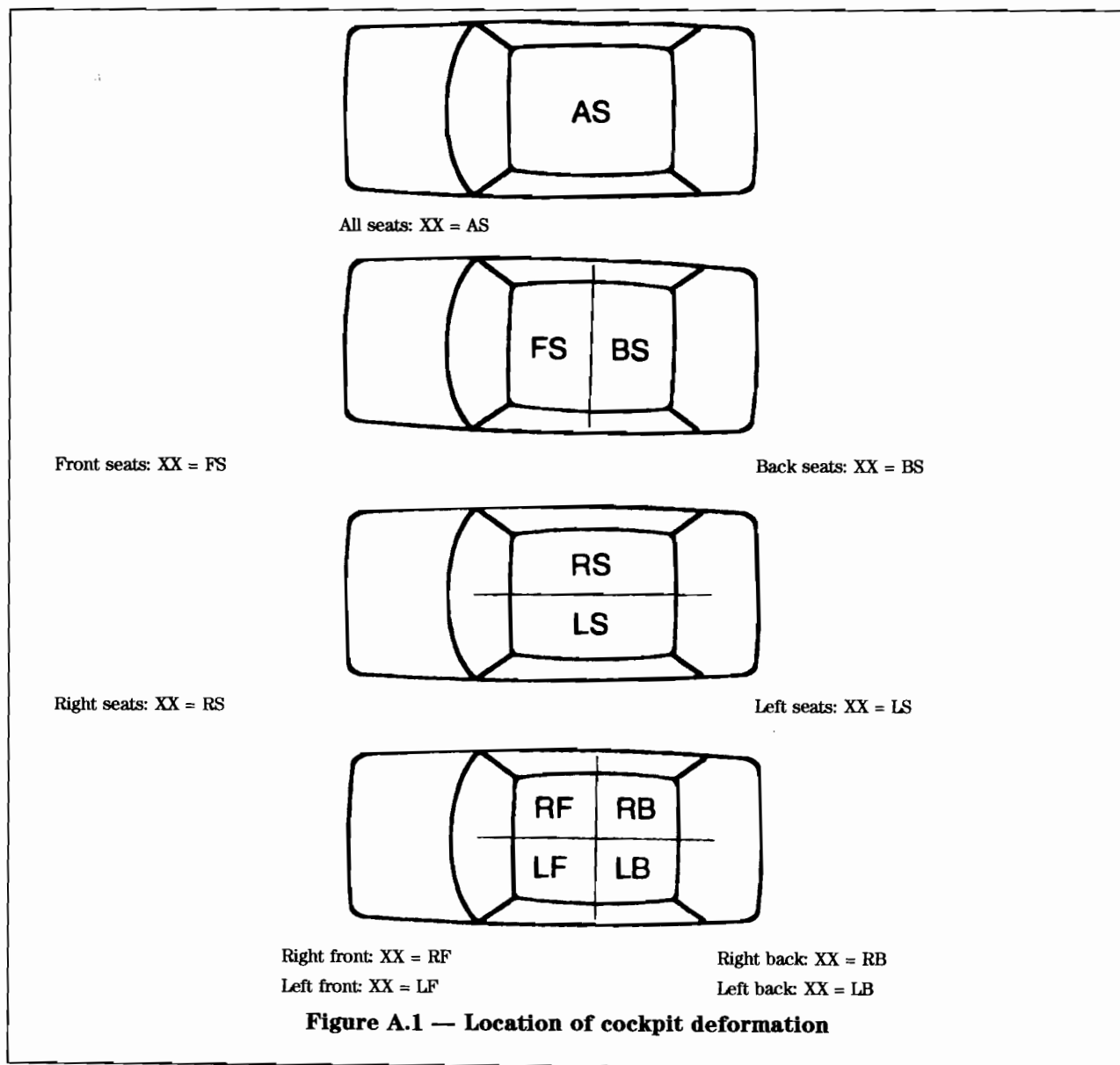
The location of cockpit deformation is indicated by the first two alphabetic characters XX, as indicated in Figure A.1.

**A.3 Extent of the deformation**

The seven sub-indices *a, b, c, d, e, f* and *g* indicate the percentage of reduction of seven interior dimensions (see Figure A.2): The value of each of the seven numeric sub-indices shall be determined by the following scale:

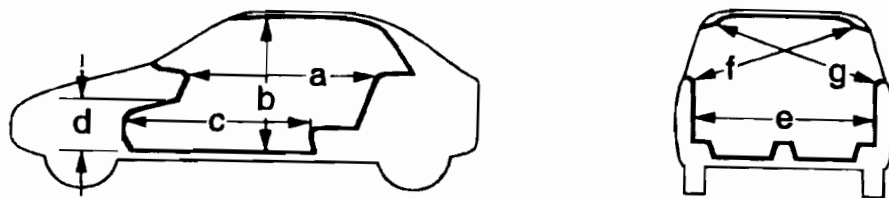
- 0 if the reduction is less than 3 %;
- 1 if the reduction is more than 3 % and less than or equal to 10 %;
- 2 if the reduction is more than 10 %.

When some of the reductions exceed 10 %, photographic description of the deformed parts shall be included.



**Figure A.1 — Location of cockpit deformation**

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- a distance between the dashboard and the top of the rear seat;
- b distance between the roof and the floor panel;
- c distance between the rear seat and the motor panel;
- d distance between the lower dashboard and the floor panel;
- e interior width;
- f distance between the lower edge of the right window and the upper edge of the left window;
- g distance between the lower edge of left window and the upper edge of right window.

Figure A.2 — Interior dimensions

#### A.4 Examples

When a side impact on the right side reduces  $e$  and  $f$  by 14 % and  $g$  by 7 % for the right seats, the reduction of all the remaining dimensions being below 3 %, the VCDI index will be: RS0000221.

When, in an end-on impact, distance  $a$  is reduced by 8 % and  $c$  by 12 % at the front right seat, all other reductions remaining below 3 %, the VCDI index will be: RF1020000.

### Annex B (informative)

#### Impact kinetic energy and theoretical average force

##### B.1 Average force from kinematics

In the first part of a successful collision against a safety barrier, the component, perpendicular to the barrier, of the velocity of the centre of gravity of the vehicle should decrease from its initial value

$$V_n = V \sin \alpha \quad (\text{B.1})$$

to null; if  $S_n$  and  $\bar{a}_n$  are, respectively, the displacement and the average acceleration of the vehicle centre of gravity in the direction perpendicular to the barrier, then in the first phase:

$$\bar{a}_n = \frac{V_n^2}{2S_n} \quad (\text{B.2})$$

and, accordingly, the average force acting on the mass  $M$  of the vehicle during the same phase is:

$$F = M\bar{a}_n = \frac{MV_n^2}{2S_n} \quad (\text{B.3})$$

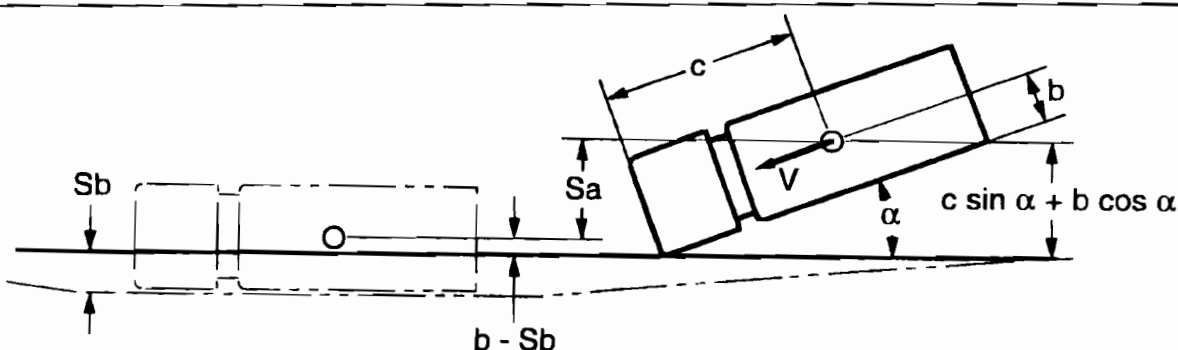


Figure B.1 — Displacement of the centre of gravity



**B.2 Average force from an energy balance**

The same result can be obtained from a simple energy balance. In fact during the first phase of the impact the lateral kinetic energy of the vehicle:

$$T = \frac{MV_n^2}{2} \tag{B.4}$$

should be balanced by the work  $W_n = \bar{F}S_n$  of the lateral force acting on the vehicle centre of gravity; hence:

$$\frac{MV_n^2}{2} = \bar{F}S_n$$

whence:

$$F = \frac{MV_n^2}{2S_n} \tag{B.5}$$

**B.3 Average force as a function of barrier displacement**

With reference to Figure B.1, the space  $S_n$  travelled by the centre of mass is approximately:

$$S_n = c \sin a + b(\cos a - 1) + S_b \tag{B.6}$$

where  $S_b$  is the maximum dynamic deflection of the traffic face of the barrier (more precisely,  $S_b$  should be the sum of the barrier deflection plus a part of the vehicle crumpling).

Thus, combining the preceding expressions the average force can be eventually expressed as:

$$\bar{F} = \frac{M(V \sin a)^2}{2[c \sin a + b(\cos a - 1) + S_b]} \tag{B.7}$$

The force  $\bar{F}$  gives the order of magnitude of the interaction between the vehicle and the barrier during the impact. It is useful for a first evaluation of the total force acting on barrier anchorages and of the severity for the colliding vehicle.

$\bar{F}$  is a force averaged with respect to lateral displacement, i.e.:

$$\bar{F} = \frac{1}{S_n} \int_0^{S_n} F(s) ds \tag{B.8}$$

Theoretical and experimental evidence shows that a significant maximum value of the force  $F(s)$ , to be considered as a measure of the maximum action on barrier anchorages, is 2,5 times larger than  $\bar{F}$ .

**B.4 Examples**

Table B.1 reports the kinetic energies, computed using equation B.4 pertaining to the specified performance classes, together with the average forces computed using equation B.7 for some example values of barrier displacement.

**Annex C (informative)**

**Vehicle acceleration — Measurement and calculation methods**

**C.1 Introduction**

During an impact the acceleration of a vehicle may vary sensibly from one point to another of the vehicle itself due to angular velocities and angular accelerations. Therefore, the measure taken at a single point may not be enough to determine the complete acceleration field within the vehicle.

In general, during a collision there is an internal portion of the vehicle that remains more or less rigid, apart from structural vibrations which are filtered out when the prescribed 60 Hz filter is applied.

**Table B.1 — Containment levels**

Containment level	Kinetic energy kJ	Traffic face deflection					
		m					
		0,1	0,4	0,8	1,2	1,6	2,0
Average force $\bar{F}$							
kN							
T1	6,2	16,8	9,3	5,8	4,2	3,3	2,7
T2	21,5	36,5	24,2	16,7	12,7	10,3	8,6
T3	36,6	46,7	33,8	24,7	19,4	16,0	13,6
N1	43,3	59,2	42,0	30,3	23,7	19,4	16,5
N2	81,9	112,0	79,4	57,2	44,7	36,7	31,1
H1	126,6	93,6	76,6	61,7	51,6	44,4	38,9
H2	287,5	133,0	116,8	100,4	88,1	78,5	70,8
H3	462,1	266,4	227,1	189,8	163,0	142,9	127,1
H4a	572,0	311,3	267,6	225,4	194,7	171,4	153,1
H4b	724,6	269,1	242,1	213,6	191,1	172,8	157,8

This annex presents two methods for determining the complete acceleration of the vehicle, considered as a rigid body, at a certain time, from measures taken at the same time. The sensors for these measures should be mounted in locally stiff points of the part of vehicle structure that behaves rigidly.

The knowledge of the complete acceleration may be needed for computing the acceleration of different points of the vehicle, or to reconstruct the vehicle path by integration.

### C.2 Acceleration in a rigid body

The acceleration  ${}_p a$  of any point P of a rigid body, in vector notation, may be expressed as:

$${}_p a = {}_c a + \omega \times R + \omega \times (\omega \times R) \quad (C.1)$$

where:

$${}_p a \equiv \begin{Bmatrix} p a_x \\ p a_y \\ p a_z \end{Bmatrix} \text{ is the acceleration of the generic point P;}$$

$${}_c a \equiv \begin{Bmatrix} c a_x \\ c a_y \\ c a_z \end{Bmatrix} \text{ is the acceleration of a datum point C;}$$

$$\omega \equiv \begin{Bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{Bmatrix} \text{ is the angular velocity of the rigid body;}$$

$R = P - C$  is the radius vector from point C to point P; Alternatively, equation (C.1) can be also put in the form:

$${}_p a = {}_c a + \dot{\omega} \wedge R + (\omega \cdot R) \omega - (\omega \cdot \omega) R \quad (C.2)$$

where the point represents scalar product, the dot ( $\cdot$ ) represents derivation with respect to time and the symbol  $\wedge$  the vector product.

Then to know the acceleration  ${}_p a$  of any point P of a rigid body at a certain time  $t$ , one needs to know the position  $R$  of the said point and nine kinematic parameters, i.e. the three components of  ${}_c a$ , the three components of  $\omega$  and the three components of  $\dot{\omega}$ , all at the same time  $t$ .

### C.3 Measurement by 12 linear transducers

Equation (C.1), in matrix notation, can be also written as:

$$\{p a\} = \{c a\} + [A] \{R\} \quad (C.3)$$

where:

$$[A] = \begin{bmatrix} -\omega_y^2 - \omega_z^2 & \omega_x \omega_y + \dot{\omega}_z & \omega_x \omega_z + \dot{\omega}_y \\ \omega_x \omega_y + \dot{\omega}_z & -\omega_x^2 - \omega_z^2 & \omega_y \omega_z - \dot{\omega}_x \\ \omega_x \omega_z - \dot{\omega}_y & \omega_y \omega_z + \dot{\omega}_x & -\omega_x^2 - \omega_y^2 \end{bmatrix}$$

Instead of the nine kinematic parameters it may be easier to take as unknowns 12 parameters, i.e. the three components of  ${}_c a$  and all the nine elements of matrix  $A$ , as follows.

Three linear accelerometers, aligned with the vehicle axes  $x$ ,  $y$  and  $z$ , are mounted on a single block at point C (which can be any suitable point), and in each of three other suitable points  ${}_1 P$ ,  ${}_2 P$  and  ${}_3 P$ . The four points should not lie in the same plane.

These 12 accelerometers give the measure of  $\{c a\}$  plus the accelerations  $\{{}_1 a\}$ ,  $\{{}_2 a\}$  and  $\{{}_3 a\}$ , of the three known points  ${}_1 P$ ,  ${}_2 P$  and  ${}_3 P$ .

For each point  ${}_i P$ , equation (C.4) can be put in the form:

$$\{i \Delta a\} = [A] \{i R\}, \quad (i = 1, 2, 3) \quad (C.5)$$

where:

$$\{i \Delta a\} = \{i a\} - \{c a\} \quad (C.6)$$

By introducing the matrices ( $3 \times 3$ ):

$$[\Delta a] = [{}_1 \Delta a \quad {}_2 \Delta a \quad {}_3 \Delta a], \quad [R] = [{}_1 R \quad {}_2 R \quad {}_3 R] \quad (C.7)$$

the three matrix equations (C.6) can be synthetically written as:

$$[\Delta a] = [A][R] \quad (C.8)$$

that can be easily solved obtaining the unknown matrix  $[A]$  in the form:

$$[A] = [\Delta a][R]^{-1}, \text{ or } [A]^T = [R]^{-T}[\Delta a]^T \quad (C.9)$$

Solution (C.9) is possible only if matrix  $[R]$  is non-singular, and this requires that the four points  ${}_c P$ ,  ${}_1 P$ ,  ${}_2 P$  and  ${}_3 P$  do not lie in a plane.

The angular acceleration  $\dot{\omega}$  can be easily obtained from the antisymmetrical part of matrix  $[A]$ :

$$\frac{1}{2}[A] - \frac{1}{2}[A]^T = \begin{bmatrix} 0 & -\dot{\omega}_x & \dot{\omega}_y \\ \dot{\omega}_z & 0 & -\dot{\omega}_x \\ -\dot{\omega}_y & \dot{\omega}_x & 0 \end{bmatrix} \quad (C.10)$$

However, the components of the angular velocity cannot be obtained uniquely nor accurately from the symmetrical part of matrix  $[A]$ . So this method, which is very straightforward for computing the acceleration of any point of the vehicle, is not recommended for path reconstruction.

When the acceleration  $\{c a\}$  and the matrix  $[A]$  are known, the acceleration of any point P of the vehicle can be easily determined by means of equation (C.3).

### C.4 Measurement by six linear and three angular transducers

This method requires six linear accelerometers plus three angular rate transducers. Three linear accelerometers and the angular velocity sensors are placed, on a single block, at the datum point C. The three linear accelerometers and the three angular velocity transducers are oriented as the vehicle axes  $x$ ,  $y$  and  $z$ .

This gives a direct measure of  ${}_c a$  and  $\omega$ , so only three unknowns remain to be determined, i.e. the components of  $\dot{\omega}$ . These can be obtained by adding only three linear accelerometers, as follows.

Let any of the latter three accelerometers be put at point  ${}_i P$  in the direction of the unit vector  ${}_i n$  ( $i = 1, 2, 3$ ); upon scalar multiplication by  ${}_i n$ , equation (C.2) takes the form:

$${}_i m \cdot \dot{\omega} = p_i \tag{C.11}$$

where:

${}_i R = {}_i P - C$  is the position vector of  ${}_i P$ ;

${}_i m = {}_i R \wedge {}_i n$ ;

$P_i = a_i - {}_c a_i - (\omega \cdot {}_i R)\omega_i + (\omega \cdot \omega)R_i$ ;

$a_i = {}_i a \cdot {}_i n$  is the measurement from the sensor at point  ${}_i P$ ;

${}_c a_i = {}_c a \cdot {}_i n$  is the component of  ${}_c a$  in the direction of  ${}_i n$ ;

$\omega_i = \omega \cdot {}_i n$  is the component of  $\omega$  in the direction of  ${}_i n$ ;

$R_i = {}_i R \cdot {}_i n$  is the component of  ${}_i R$  in the direction of  ${}_i n$ .

Putting together equation (C.11) for the measurements of the latter three transducers, the following final form is obtained:

$$[M] \{\dot{\omega}\} = \{p\} \tag{C.12}$$

where:

$$[M] = \begin{bmatrix} 1m_x & 1m_y & 1m_z \\ 2m_x & 2m_y & 2m_z \\ 3m_x & 3m_y & 3m_z \end{bmatrix}; \{\dot{\omega}\} = \begin{Bmatrix} \omega_x \\ \omega_y \\ \omega_z \end{Bmatrix}; \{p\} = \begin{Bmatrix} p_x \\ p_y \\ p_z \end{Bmatrix} \tag{C.13}$$

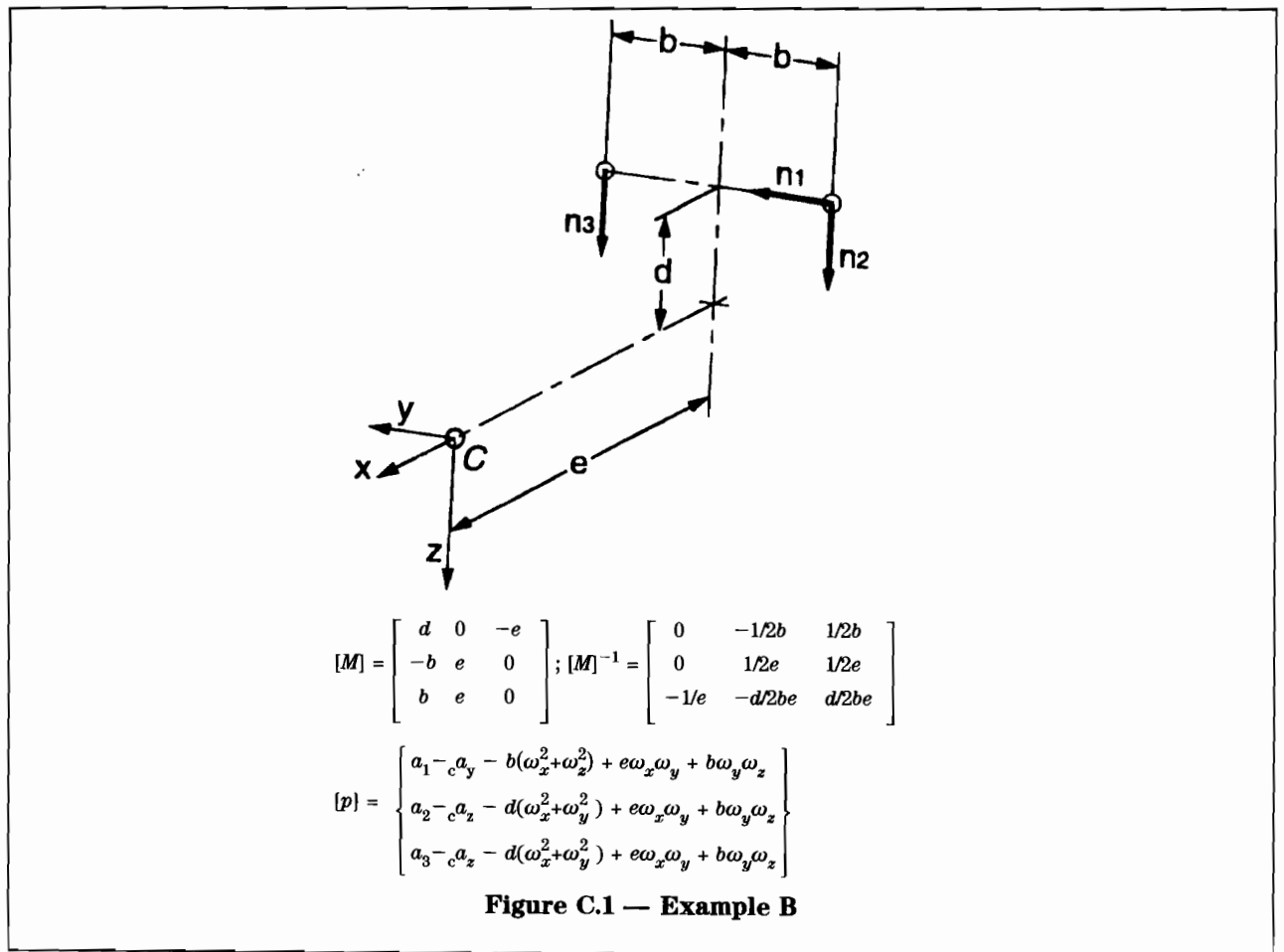
From equation (C.12) the angular acceleration is found in the form:

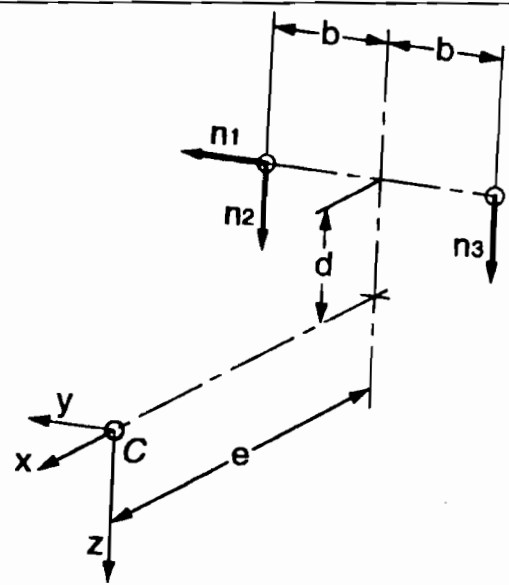
$$\{\dot{\omega}\} = [M]^{-1} \{p\} \tag{C.14}$$

Such a solution is possible only if matrix  $[M]$  is non-singular, and this requires that the points  ${}_i P$  and the orientations  ${}_i n$  ( $i = 1, 2, 3$ ) of the sensor be carefully selected.

With this all the nine kinematic parameters, i.e.  $\{{}_c a\}$ ,  $\{\omega\}$  and  $\{\dot{\omega}\}$  are known. They can be used to compute the acceleration of any point  $P$  of the vehicle with equations (C.1), (C.2) or (C.3), or to reconstruct the vehicle path with a suitable procedure.

A good choice of the position and of the orientation of the transducers is reported in the following examples, where the point  $C$  is in the  $xz$  plane (symmetry plane), close to the vehicle centre of gravity, and the remaining





$$[M] = \begin{bmatrix} d & 0 & -e \\ b & e & 0 \\ -b & e & 0 \end{bmatrix}; [M]^{-1} = \begin{bmatrix} 0 & 1/2b & -1/2b \\ 0 & 1/2e & 1/2e \\ -1/e & -d/2be & -d/2be \end{bmatrix}$$

$$[p] = \begin{bmatrix} a_1 - c_y + b(\omega_x^2 + \omega_y^2) + e\omega_x\omega_y + d\omega_y\omega_z \\ a_2 - c_z - d(\omega_x^2 + \omega_y^2) + e\omega_x\omega_y + b\omega_y\omega_z \\ a_3 - c_z - d(\omega_x^2 + \omega_y^2) + e\omega_x\omega_y + b\omega_y\omega_z \end{bmatrix}$$

Figure C.2 — Example B

three accelerometers are mounted at two points, symmetrical with respect to the  $xz$  plane. Other good choices are also possible.

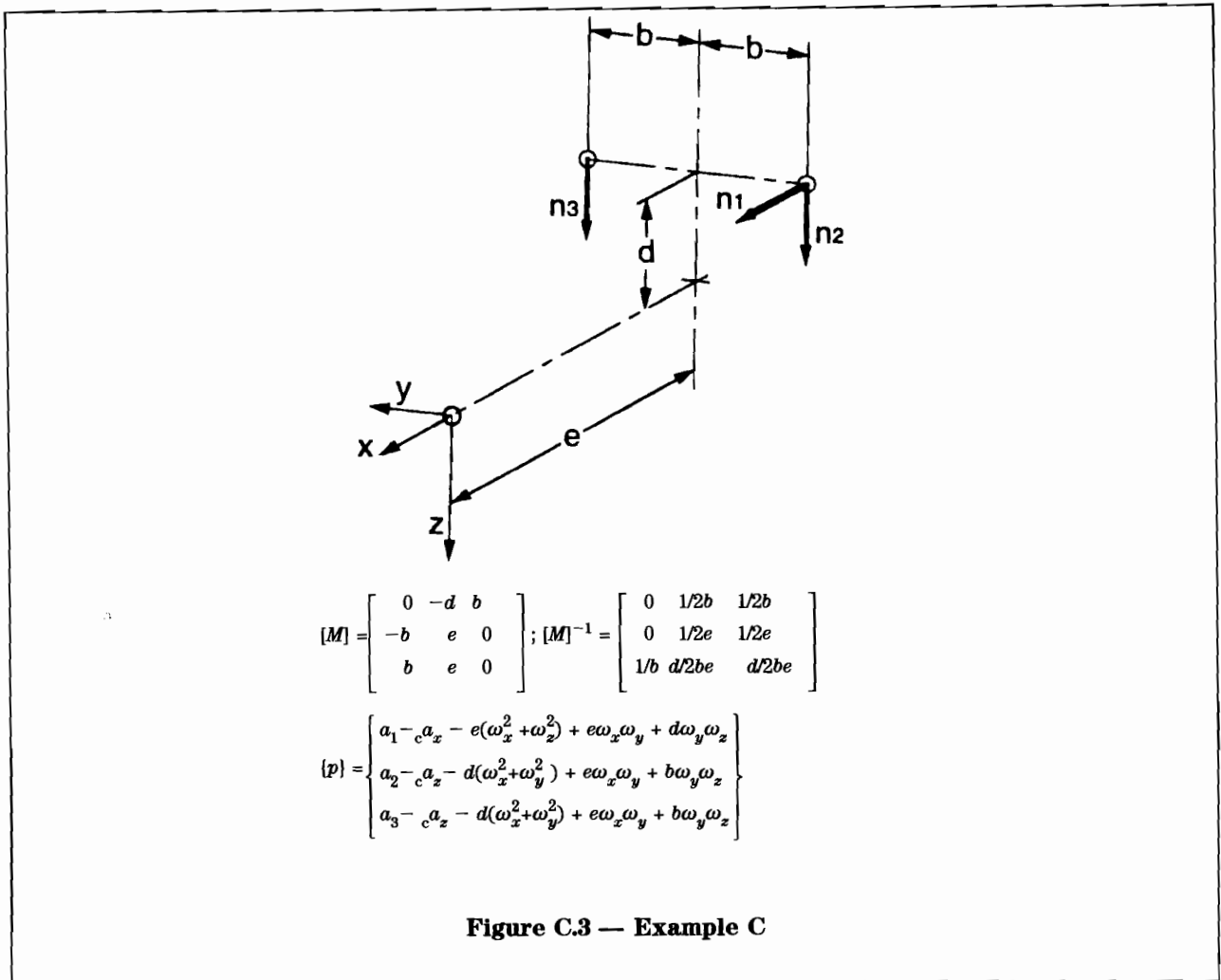


Figure C.3 — Example C

**C.5 Remarks**

The first method proposed requires only linear acceleration transducers, but in a redundant number; it is straightforward for the evaluation of the acceleration of any point of the vehicle.

The second method, which requires a minimum number of transducers (six linear acceleration and three angular velocity), is more suitable when path reconstruction has to be made. Among the three layouts shown in the examples, A is mostly recommended for collisions on the right side, B for collisions on the left side and C for end on collisions.

In any case, the accuracy and the cost of the different transducers should also be considered in any comparison of the two methods.

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