PD CEN/TR 16303-2:2012

BSI Standards Publication

Road restraint systems — Guidelines for computational mechanics of crash testing against vehicle restraint system

Part 2: Vehicle Modelling and Verification

raising standards worldwide™

National foreword

This Published Document is the UK implementation of CEN/TR 16303-2:2012.

The UK participation in its preparation was entrusted by Technical Committee B/509, Road equipment, to Subcommittee B/509/1, Road restraint systems.

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

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2012

ISBN 978 0 580 75311 4

ICS 13.200; 93.080.30

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 March 2012.

Amendments issued since publication

Amd. No.	Date	Text affected

TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

CEN/TR 16303-2

January 2012

ICS 13.200; 93.080.30

English Version

Road restraint systems - Guidelines for computational mechanics of crash testing against vehicle restraint system - Part 2: Vehicle Modelling and Verification

Dispositifs de retenue routiers - Recommandations pour la simulation numérique d'essai de choc sur des dispositifs de retenue des véhicules - Partie 2: Composition et vérification des modèles numériques de véhicules

Rückhaltesysteme an Straßen - Richtlinien für Computersimulationen von Anprallprüfungen an Fahrzeug-Rückhaltesysteme - Teil 2: Fahrzeugmodellierung und Überprüfung

This Technical Report was approved by CEN on 8 November 2011. It has been drawn up by the Technical Committee CEN/TC 226.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. CEN/TR 16303-2:2012: E

Contents

Page

Foreword 3

Introduction 4

1 Scope 5

2 Normative references 5

3 General considerations on the modelling techniques of a vehicle 5

4 Step by step development of a vehicle for crash test analysis 7

5 Validation procedures of a vehicle for crash test analysis 8

Annex A Recommendations for the mesh of Finite Element vehicle models addressed to crash simulations 11

Annex B Recommendations and criteria for multi body vehicle models addressed to crash simulations 22

Annex C Test methodology 23

Annex D Phenomena importance ranking table for vehicles 27

Annex E Phenomena importance ranking table for test item and vehicle interaction 29

Bibliography 30

Foreword

This document (CEN/TR 16303-2:2012) has been prepared by Technical Committee CEN/TC 226 “Road equipment”, the secretariat of which is held by AFNOR.

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

This document consists of this document divided in five Parts under the general title: Guidelines for Computational Mechanics of Crash Testing against Vehicle Restraint System:

— *Part 1: Common reference information and reporting*

— *Part 2: Vehicle Modelling and Verification*

— *Part 3: Test Item Modelling and Verification*

— *Part 4:Validation Procedures*

— Part 5: *Analyst Qualification*[1]

---

[1] In preparation

Introduction

This part of CEN/TR 16303 is informative. It gives general information for the development of a vehicle model for crash test simulation against vehicle restrain system.

Two different categories of vehicle models can be identified. The first category consists of a detailed model (usually finite element) of a vehicle or of a portion of it, typically used in the automotive industry to assess the structural performance and properties of the vehicle. A second type of vehicle model (finite element or multi-body), instead, is typically used to assess the barrier performance in the simulation of full-scale crash tests. In this case, a less detailed model is required, in order to obtain a computationally cost-effective tool for the analysis of several different crash scenarios. At the same time, it is mandatory to reproduce faithfully the correct inertial properties and outer geometry of the vehicle.

This Part of the guideline is meant to provide the user with all the information necessary to develop a complete and efficient numerical model of a vehicle in order to properly simulate a crash event (second category of vehicle above). It is not convenient to use a very detailed model, because of the unaffordable increase in the computational costs. In this perspective, the vehicle model can be regarded as a tool for the analysis of a crash event.

1 Scope

The aim of this Technical Report is to provide a step-by-step description of the development process of a reliable vehicle model for the simulations of full-scale crash tests giving the reader a first synthetic summary of problems encountered in the different steps of the vehicle modelling process.

2 Normative references

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

N/A

3 General considerations on the modelling techniques of a vehicle

3.1 General

Particular attention shall be paid on the modelling of vehicular kinematics and of the components that realize it: front and rear suspensions, wheels, steering system, etc. The geometry of the vehicle shall be reproduced correctly to simulate the interaction with the barrier. The model shall include only significant parts and few details (internal parts should be modelled only regarding their inertial properties, etc.) in order to reduce the computational cost of the model.

3.2 Finite Element and Multi-body approaches

Two main modelling approaches can be considered, using two different analysis tools: the Finite Element Method (FEM) and the Multi-Body (MB) approach. Both methods are widely known and broadly used in many fields of engineering, including the Automotive Industry.

The first method allows the user to build a very detailed vehicle model and to assess global results such as the barrier or vehicle performance in a crash test as well as the stress data in a local area of the vehicle. As a counterpart, a FEM analysis requires significant computational costs, thus proving less valid for parametric studies where a large number of simulations may be required.

Crash tests finite element (FE) simulations are usually run with a dynamic, non-linear and explicit finite element code. Computer runtime is usually significant, with the order of 30-40 hours on a 2,4 GHz personal computer for the simulation of a full-scale crash test with an effective simulated time of 0,25 second. In fact, the model must include not only the vehicle model, but also several meters of roadside barriers (depending on the barrier type, up to 80 meters of barrier) to faithfully reproduce the interaction between the vehicle and the barrier and the boundary conditions. The integration time step is controlled by the minimum dimension of the smallest element of the FE mesh, therefore, the mesh size shall be a trade-off between the need for geometrical and numerical accuracy and computational cost: large elements guarantee a high time step but poor accuracy of the model and possible instabilities, while small elements give a better accuracy but a smaller time step. General criteria for the mesh can be identified. The most significant parts of the vehicle shall be modelled explicitly with a detailed mesh (vehicle body, wheels, etc.). Other parts can be modelled implicitly, reproducing their inertial properties (engine) or their function and kinematics (suspension and steering systems).

On the other hand, the MB approach consists roughly in modelling the vehicle as a number of rigid bodies connected by means of joints with specified stiffness characteristics. The method is particularly suitable to assess the kinematics of the vehicle, while less applicable to determine data about levels of stress and strains. When reliable and validated data are available, the MB approach is very useful to perform parametric studies, since the computational cost of the analysis can be dramatically less than that of the corresponding FEM analysis.

3.3 General scheme of a vehicle

Three main categories of vehicles can be identified:

a) passengers cars;

b) heavy goods vehicles (HGVs);

c) buses.

Despite their differences, basically in terms of mass and geometry, they share many common elements:

- frame;
- body;
- suspensions (front and rear);
- wheels;
- steering system;
- glasses;
- engine block;
- vehicle’s interiors.

Regarding the vehicle structure, it must be pointed out that two main different structural options can be identified: the body-on-frame vehicle, typical for trucks and HGVs and the unit-body vehicle, typical for passenger cars. In the first case, three structural modules that are bolted together to form the vehicle structure can be identified: frame, cabin and box or bed (for a pick-up truck for example). In the second case, the vehicle combines the body and frame into a single unit constructed from stamped sheet metal and assembled by spot welding or other fastening methods. This structure is claimed to enhance whole vehicle rigidity and provide for weight reduction.

Suspensions can also be subdivided into two main groups: dependent and independent. Generally, independent suspensions are used for passenger cars and dependent suspensions are employed in commercial vehicles and buses.

Wheels can be single or coupled. The latter configuration is customary for rear wheels of HGVs and buses.

3.4 Vehicle validation considerations

Once the vehicle model has been built, it shall be validated with simple tests, both components tests and full-model tests, observing the global response of the model and the behaviour of the single parts (suspensions, wheels). Numerical stability of the model shall be assessed. Subsequently, the model can be used to simulate full-scale crash tests.

The same validation approach shall be applied both to FEM and MB modelling. This document can be applied to different modelling techniques, codes or vehicles. Despite different models, the same level of validation shall be required if these models will be applied during the certification process.

Some general comments can be emphasized to accurately predict ASI and THIV, as calculated from a vehicle body mounted accelerometer:

a) correct representation of stiffness, strength and inertial properties of the vehicle body

   ⇒ part strength, crush mode and timing of front wing, engine firewall, bonnet, A Pillar, floor and other parts affect the accelerations recorded;

b) correct representation of tyre interaction with the vehicle body, and hence tyre stiffness

   ⇒ for stiffer barriers especially, how the tyre loads the sill and wheel arch affects the accelerations;

c) accurate capturing of steering, suspension motion, suspension spring and damper properties

   ⇒ for weak post systems in particular, longitudinal acceleration is greatly influenced by whether a wheel strikes a post, which can be determined by how the front wheels react/steer from previous strikes;

   ⇒ lateral accelerations are affected by the vehicles ability/inability to steer

d) sufficient detail for modelling is required for representative vehicle behaviour

   ⇒ reducing the model detail and integrity cannot be substituted for lack of computational resource;

   ⇒ accelerometer sampling rate can affect results and needs to set at an appropriate level to give results convergence;

e) a combination of element size and time step can produce mass scaling of the vehicle. Mass scaling should be kept to a minimum (aim at less than 2 %) as mass added to the vehicle on initialisation could affect the impact results. The added mass should not be concentrated in critical areas.

In building a model we make assumptions on what effects are important and to level of accuracy to capture those effects. It is only by conducting a physical test that we discover what physical effects actually occur, and the relative importance of those effects.

It is also possible that poorly constructed models can produce, what appear to be accurate high level results that match test e.g. peak ASI, THIV and PHD, however, the underlying accelerations can be far from reality. Therefore detailed analysis of the elements making up the high level results need to be fully understood.

4 Step by step development of a vehicle for crash test analysis

Annex A refer to the development of a Finite Element model of a vehicle. In particular:

- A.1 focuses on the vehicle components to be modelled, describing extensively the function of the component and its role in the model as well as some of the *ad hoc* techniques to achieve an efficient model of the part. On the basis of these considerations the user can basically develop any vehicle model, be it a passenger car or a pick-up truck.

- A.2 deals with organisation aspects of the model. Models, in fact, often need to be used by different organisations and pass from user to user. It is, therefore, important that the models have a standard structure and an organisation predictable and easy to understand. A modular model structure is recommended and extensively presented in this annex.

- A.3 a brief presentation of material models suitable for dynamic analyses is provided. Materials and their properties are fundamental aspects of a reliable model, since the vehicle models that are objective of this manual are going to be used for the simulation of a dynamic event.

- A.4 includes specific recommendations on the mesh features.

Annex B refer to the development of a Multi-Body model of a vehicle. In particular:

5 Validation procedures of a vehicle for crash test analysis

5.1 General

This clause deals with the validation phase of the model. Significant numerical tests are recommended to check the stability and reliability of the model.

5.2 Test methodology

5.2.1 General

The finite element model and the multi body vehicle model shall be validated with the same requirements and limit.

The vehicle will be considered validated, for a certain class of impacts, if the comparison between simulation and testing will fit inside the limits described by this Validation Roadmap (tests description is in Annex C).

The Validation Roadmap includes several simple tests made to ensure the numerical stability and the capability of the numerical model. There are two classes of tests: component test and full scale vehicle test.

5.2.2 Components tests

Simulated tests shall be performed on vehicle components to demonstrate the capabilities of the sub structures.

The tests of components involve mainly the suspension system; they require simulations and correlations with experimental tests. The results from tests on front and rear suspension should be compared with simple pendulum tests.

Description of tests is in C.1

5.2.3 Full scale vehicle test

During these phase all the vehicle shall be modelled.

Different typologies of tests are scheduled:

- Idle tests: this analysis is needed to guarantee the stability of the vehicle (Description of test is in C.2);

- Linear/circular track tests: this second typology is made to control the performances of the vehicle while is moving or turning with a fixed or variable radius (Description of tests are in C.3);

- Curb test: The vehicle model is forced to override curbs to test the response of the suspension system and wheels to small impacts (Description of tests are in C.4);

- Full-scale vehicle test: these tests are made in order to assess the global response of the vehicle while impacting against a rigid wall and a deformable barrier impacts (Description of tests are in C.5).

5.3 Acceptance criteria and results to be provided

The simulations described in Clause 6 of this guideline are required to demonstrate the stability of the model regarding numerical integration and suspension system. The model shall respond without any instability during all the simulation.

In Table 1 are described all the result that shall be provided for each test:

Table 1 — Vehicle test list purposes and results

N°	Type of simulation	Scope of simulation	Results to be provided
1.1	Isolated suspension	Verify the correct behaviour of both the shock absorber and the failure of the system	Animation showing the movement of the suspension. Load deflection history of the load transferred to the wheel. Wheel orientation versus time
1.2.1	Suspension load. Each wheel shall be loaded separately.	Verify suspension kinematics and loading unloading capabilities. Uncoupling of shaking / steering movement (for front wheels).	Animation showing the movement of the suspension. Load deflection history of the load transferred to the wheel. Wheel orientation versus time
1.2.2	Suspension load. Frontal suspension and rear suspension wheel shall be loaded separately. Symmetrical load	Verify suspension kinematics and loading unloading capabilities. Suspensions coupling due to stabilizer bar.	Animation showing the movement of the suspension. Load deflection history of the load transferred to the wheel. Wheel orientation versus time
1.2.3	Suspension load. Frontal suspension and rear suspension wheel shall be loaded separately. Non-symmetrical load	Verify suspension kinematics and loading unloading capabilities	Animation showing the movement of the suspension. Load deflection history of the load transferred to the wheel. Wheel orientation versus time
2.1	Vehicle in idle	To verify stability of the vehicle model itself	Acceleration time histories. Kinetic and total energy time histories.
3.1	Linear track.	To verify stability of the vehicle, steering and suspension system.	Acceleration time histories. Kinetic and total energy time histories.
3.2	Circular track.	To verify stability of vehicle, steering and suspension system	Acceleration time histories. Kinetic and total energy time histories.
4.1	Curb testing: Both front wheels	To verify stability of the suspension and steering system	Acceleration time histories. Kinetic and total energy time histories.
4.2	Curb testing: Both rear wheels	To verify stability of the suspension and steering system	Acceleration time histories. Kinetic and total energy time histories.
4.3	Curb testing: Right front wheel	To verify stability of the suspension and steering system	Acceleration time histories. Kinetic and total energy time histories.

Table 1 *(continued)*

N°	Type of simulation	Scope of simulation	Results to be provided
4.4	Curb testing: Left front wheel	To verify stability of the suspension and steering system	Acceleration time histories. Kinetic and total energy time histories.
4.5	Curb testing: Right rear wheel	To verify stability of the suspension and steering system	Acceleration time histories. Kinetic and total energy time histories.
4.6	Curb testing: Left rear wheel	To verify stability of the suspension and steering system	Acceleration time histories. Kinetic and total energy time histories.
5.1	Full scale crash against a rigid wall	To verify the capability of suffering strong deformations	Acceleration time histories. Kinetic and total energy time histories.
5.2	Full scale crash against a deformable barrier.	To verify the capability of representing the interaction with a real barrier.	Comparison with experimental results according to the Validation Roadmap

5.4 Verification of model validation

Model validation should be verified by the Acceptance Body according to the validation Guideline. To preserve the property of models, these simulations could be run using restart files created at time zero. With this technique simulations can be run without having the original models.

The Acceptance Body, using his results, must verify the time histories reported in the validation report.

5.5 Standard Reports and Output Parameters

The validation activity shall be described inside a report. The validation report shall comply with the format given the Reporting Guideline and has to be included in the documentation enclosed with the vehicle model.

For the model validation the comparison between experimental tests and simulation shall be reported according to this Validation Roadmap.

This documentation shall contain also the history of the model and the use in already performed activities. The history shall contain also the modifications applied to the vehicle and the justification for that.

Annex A

Recommendations for the mesh of Finite Element vehicle models addressed to crash simulations

A.1 Component to be modelled

A.1.1 Frame

The function of the frame is to support all the major components or sub-assemblies that compose the complete vehicle: engine, transmission, suspensions, body, etc. As already mentioned, two different types of vehicle structure can be used:

a) separate frame;

b) integral or chassisless construction.

The first solution (separate frame), although quite popular in the past, is nowadays implemented only for commercial and off-road vehicles. In this case the frame is a distinct component and typically it consists of two C cross-section side members linked by cross members, thus contributing to the overall torsional stiffness of the structure. All these members are connected by means of rivets and bolts.

Instead, in the integral type the chassis frame is welded to, or integrated with, the body. A further development is the chassisless construction, where no chassis frame can be discerned.

Excluding the chassisless construction, in a FE model both side and cross members are usually modelled with shell elements, while connections are realized with rigid spot weld elements. Since experience shows that these links are very unlikely to fail, it is not necessary to include any failure criteria. In order to obtain the correct interaction between side and cross members, it is appropriate to define a contact interface between them, thus reproducing the effective torsional stiffness of the frame.

The connection between the frame and the other parts of the vehicle should be realized according to the parts to be linked. Generally, most of the vehicle components are rigidly linked to the frame or are coupled with some kinematical joints.

A.1.2 Vehicle body

The main role of the vehicle body is that of protecting the occupants from external events (wind and atmospheric phenomenon) and providing and adequate aerodynamics. Nevertheless, during a crash against a restraint system, the vehicle body can influence the behaviour; in fact sometimes the metal sheet of which it is composed can break and snagged between parts of the barrier. Hence the body geometry and material properties should be modelled as accurately as possible.

Customary, this part of the model is made by shell elements characterized by an appropriate thickness. The material by which the vehicle body is usually made is metal: steel or aluminium alloy. These materials can be easily modelled as elasto-plastic in almost all the finite element codes.

A.1.3 Suspensions

Suspensions are those parts of the vehicle which link the wheels to the frame; therefore they are essential in determining the vehicle dynamics. During impacts against restraint systems they play a relevant role in determining the vehicle trajectory and dynamical behaviour (roll, pitch and yaw motion).

As mentioned above, two main categories of suspensions can be discerned: dependent and independent. The former type is the simplest suspension and consists of one rigid axle to whose extremities wheels are connected. Usually, the linkage between this axle and the vehicle is made by springs (coil or leaf type). Instead, independent suspensions are characterized by a more complex geometry and can have different designs. Most car vehicles use independent suspensions and a great variety of constructive solutions have been developed during the years.

Suspensions can be modelled in two main ways: *explicitely* or *implicitely*:

- Explicit modelling means that almost all parts which compose the suspension system are modelled (using shell, solid and discrete elements). That requires a deep knowledge of the geometry of all the suspension’s parts and a quite long meshing work. Only springs and dampers can be implicitly modelled by discrete elements.

- Implicit modelling, instead, is made by defining a simplified kinematical system which should behave as faithfully as possible respect to the actual suspension. The equivalent kinematical system should be realized combining some simple rigid bodies (small shell or solid elements) by means of different joints, in order to define a sort of “multibody” component inside the finite element model. Discrete spring and damper elements should be defined in the appropriate locations, in order to model the stiffness and damping properties of the actual suspension.

The advantage of an implicit modelling is the great reduction of computational cost and the possibility to easily modify the stiffness and kinematical properties of suspensions; but, on the other hand, the realization of a trustworthy equivalent system can be more difficult than simply meshing the suspension.

A.1.4 Wheels

Wheels are those components of the vehicle which guarantee the contact with the roadway and permit the movement by rolling. Wheels are directly involved in the impact against a restraint system; the correct modelling of these parts can have a strong influence on the overall behaviour of the vehicle.

The main characteristic which should be modelled is the possibility to roll freely. In many finite element codes this is achievable defining a joint between two rigid bodies which allow a relative rotation along a specific direction.

The second factor to be taken into consideration in the development of the numerical model is the tire. The deformation of the tyre and, especially, the friction with the roadway should be considered. In particular, the presence of the air inside the tyre can be modelled using an airbag volume definition, which is often implemented in the finite element solver commonly used for crash simulations. In this case an inflation curve should be defined in order to “inflate” the volume delimited by the tyre and the rim at the first instants of the simulation.

As for the friction coefficient between the tyre and the roadway, it has been noticed from simulations performed in the past that the definition of only a static frictional coefficient with a value similar to the real one, but without the definition of a dynamic frictional coefficient, can lead to an excessive adherence of the vehicle.

To avoid this problem, in the case a dynamic frictional coefficient cannot be defined, a value 30 % lower than the actual one should be used.

Representing the physical attributes of tyres can have a significant influence on the vehicle behaviour during impact. If certain attributes are present in the physical test and not in the simulation, the simulation will not predict them.

A.1.5 Steering system

Together with suspensions, the steering capability is indeed one of the most important features which can influence the vehicle trajectory during a lateral impact against a restraint system. In particular the possibility to steer allows the front wheels to turn in the first instants of the collision, therefore conditioning the trajectory of the vehicle in the rest of the impact. This capability is even necessary to correctly determine the vehicle behaviour in the case of particular barriers which impose a desiderated trajectory, such as the New-Jersey type barriers.

The actual steering system of most cars (Figure A.1) is realized with a rack-and-pinion steering gear, in which the rack moves two lateral rods, each of which commands the respective wheel.

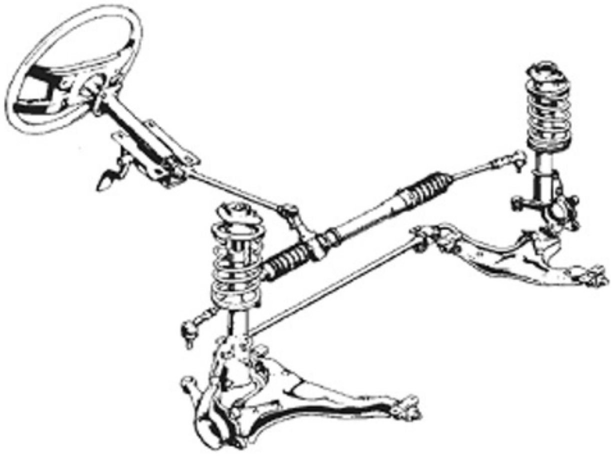
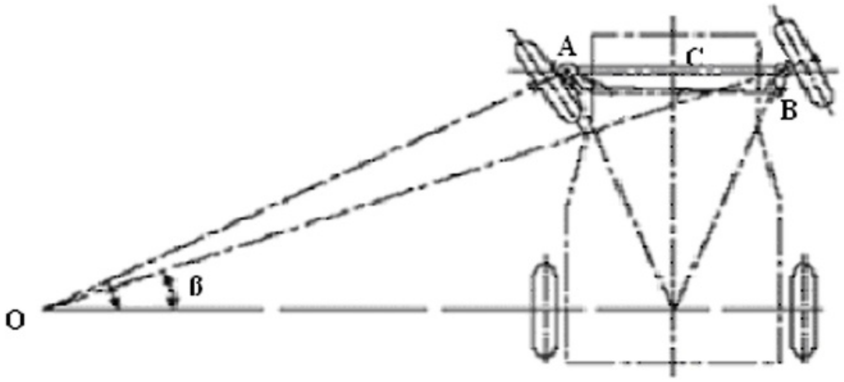


Figure A.1 — Actual steering system of a modern car

When a vehicle is turning, the wheel axes shall all intersect at a common point; that is the centre about which the vehicle as a whole is turning.

This common centre shall lie somewhere along the lines of the axis produced by the fixed rear axle. As can be seen from Figure A.2 this means that, when front wheels are steered, their axes shall be turned through different angles so that the point O of their intersection is always on that axis produced.



Key

A	rotation point of front internal wheel	O	centre of vehicle rotation
B	rotation point of front external wheel	α	steering angle of internal wheel
C	front axle	β	steering angle of external wheel

Figure A.2 — Ackerman principle of steering

Suspension properties in the normal ride range are well known and can be modelled. Properties of the wheel travel at full suspension travel or at damper lock up are at best approximations until they are correlated with tests.

Failure of suspension components such as at the wheel knuckle, joints of suspension arms etc, is very difficult to do accurately until they are correlated with tests.

Suspension pre-load should be taken into consideration.

A.2 Model Organization

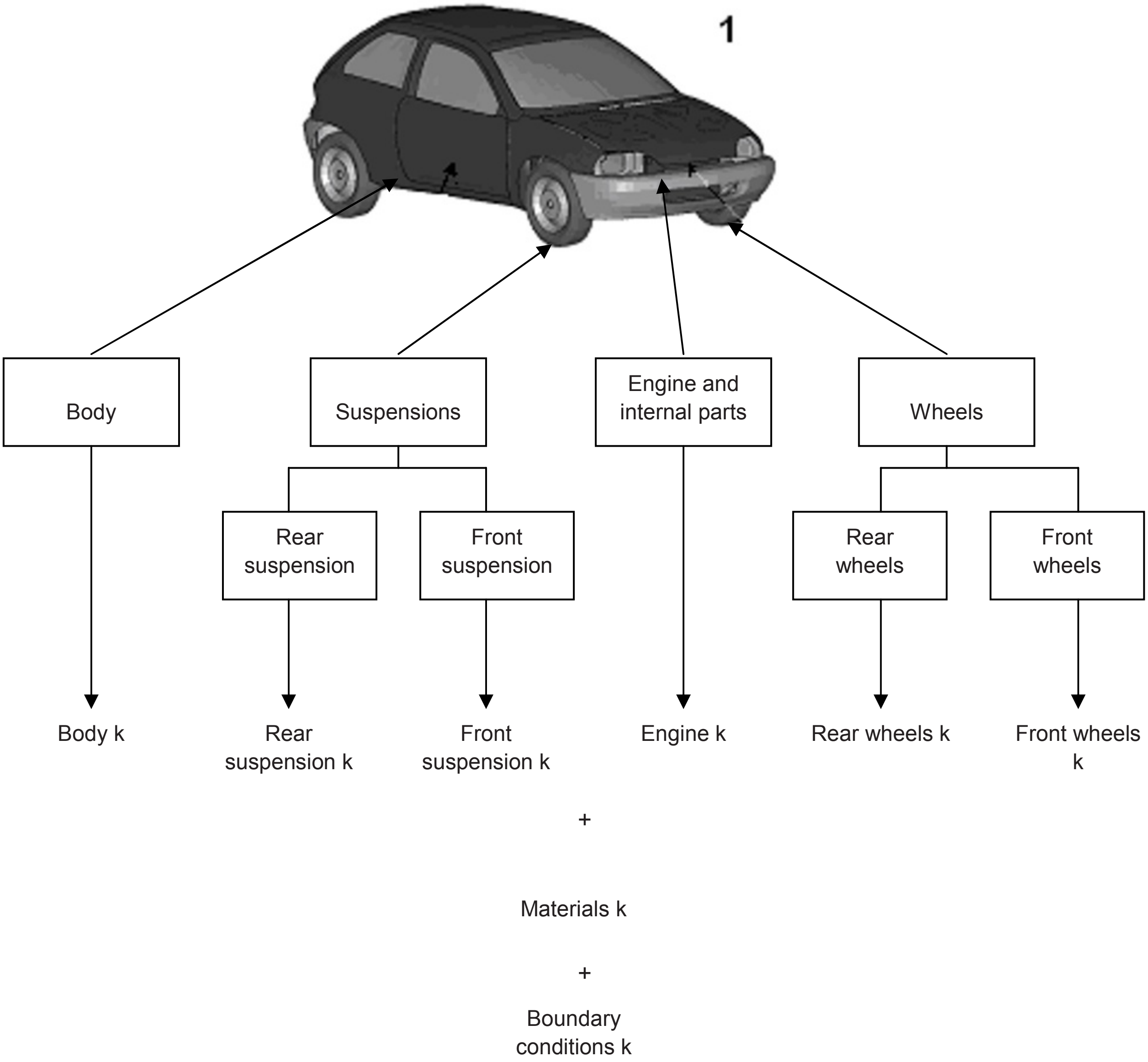
A.2.1 General consideration

A fairly detailed vehicle model is necessarily articulated and complex. In order to be able to move easily in the model, identify the nodes and elements that belong to every single part, modify the model, enhance it, remesh or refine a pre-existent mesh, it is important to define its structure and organization before actually realizing it. This organization is required also to allow a better understanding of the different components and meshing tecniques.

Vehicles are naturally composed by several subcomponents: body, engine, internal parts, suspensions, tyres, etc. It is, therefore, advisable to build the model with a *modular structure*. The term “modular structure” simply refers to the model organization: every subcomponent is contained in a separate file, while the whole model can be recalled with a main file that uses a command of file including. As an example, in LS-Dyna, this is achieved using the card **INCLUDE*.

Other two files must be considered in the structure: a first file that includes all the boundary conditions, contact definitions and constraint definitions that involve subcomponents defined in different files, and a second file where all the materials defined in the model are stored.

A possible model structure for Ls-dyna application is provided below (Figure A.3).



Key

1 Small passenger car

Figure A.3 — Sample of subcomponents subdivision for a small car

The main file would, therefore, be:

```
$ Main.k
$
$   Heading
$
*KEYWORD
*INCLUDE
\Body\Body.k
*INCLUDE
\Suspensions\Rr_susp.k
*INCLUDE
\Suspensions\Fr_susp.k
```

```
*INCLUDE
\Engine\Engine.k
*INCLUDE
\Wheels\Rr_wheels.k
*INCLUDE
\Wheels\Fr_wheels.k
*INCLUDE
Boundary_conditions.k
*INCLUDE
Materials.k
*END
```

A.2.2 Rules for the development of a modular model

Some simple rules should be followed in the development of a modular model:

- Files organization: create a file for each subcomponent, a file for global boundary conditions, contacts and constraints that involve more than one subcomponent and a “main” file that recalls all the files that compose the model. In the subcomponent file, all the parts of the subcomponent should be included, as well as the contact definitions, constraints and cards that are related only to the specific subcomponent. Files should be independent one from another when the boundary conditions file is not included, so that each subcomponent file can be opened singularly in a preprocessor environment. Files may be labeled with the version number in order to keep track of modifications to the model. In the example above, a file for material definitions has been created. This technique is particularly suitable to those situations where frequent modifications may be necessary to material definitions or material models (when different materials need to be tested or a material model need to be calibrated, etc.). In fact, in these cases, the modifications can be made in a single file, reducing the possibility of error with several material definitions placed in different files.

- Nodes and Elements numbering: nodes and elements should be numbered sequentially within each subcomponent in such a way that every part uses a distinguishable range. For instance, considering the body of the vehicle, it is composed (for simplicity) as in the example above by 6 subcomponents, each one of them will then be composed by many parts. The user can choose the range 1-100000 that can include either the total number of nodes either the total number of elements in the subcomponent. Then, for each single part a sub-range within the one assigned for the subcomponent can be used, leaving a predetermined gap between the parts. Gaps should be predicted expecting possible remeshing or mesh refinements of the parts. This technique is particularly useful to identify promptly which part or subcomponent a node or an element belongs to, for example in an error message, etc.

- Comments: all the files should be headed with a description of the modeled subcomponent, the date of the last modification and the author. Main versions of the file and major modifications should be summarized in this heading.

One major drawback of developing a model in different files could be the fact that often pre-processor applications are not able to save the model mantaining the original subdivision, but they save all the subcomponent files in a single file. So, if the user wants to translate, rotate or make any geometrical operation on a modular model, it is not possible to save the model maintaining the original subdivision of the files. For these reasons, if possible, it is advisable to reduce the number of operations to be performed on the vehicle model as far as positioning, translating or rotating the vehicle with respect to the roadside device in the impact scenario. It is, in fact, preferable to move or rotate in position the restraint system rather than the vehicle model.

When global modifications that involve the whole vehicle model cannot be avoided, these operations should be introduced manually. The modifications can be applied to each single subcomponent file or to the model as a whole when imported in a pre-processing environment. To preserve the original organization of the model, modifications should be introduced in a temporary file including the whole model (after saving a copy of the original model!), then pasted manually in each subcomponent file.

This model organization technique is particularly useful when the model is directed to a broad public of users. In fact, if different analysts need to use the model, a modular structure can be a great advantage and can make the model easy to understand in order to be further modified or adapted to different impact scen

- preferred units for the models are millimetres, Newtons, tons and seconds. These units guarantee consistency of results;
- nodal coordinates should be defined in the vehicle reference frame;
- the fiber direction for all the shell elements should be coherent (same orientation, except in case of contact definition regions).

A.3 General recommendations for the material of Finite Element vehicle models addressed to crash simulations

A.3.1 Material constitutive laws

Material constitutive laws must be consistent with the scope of the simulation. Materials can suffer large plastic deformation and failure. Material representation shall reflect these capabilities. Joints shall be represented only in parts that can be detached during barrier-vehicle crash.

A.3.2 Strain rate effect

Strain rate effect should be taken into account. The use of strain rate effect needs experimental results that are not always available. Effort must be spent to identify critical parts of the vehicle that need this feature. Vehicle model documentation shall contain all the material cards used and justifications of the constitutive models used. Strain rate parameters for many materials is important as this can affect whether a part crushes (or the depth of crush in a part) when the strain rate has an effect around the yield point. Strain rate effects can also be important at higher strains.

A.3.3 Model prediction

Using a Von Mises yield surface is an approximation to the real yield surface. Parts that definitely collapse and those that definitely do not can be predicted well. There exists a grey area of prediction for parts on the verge of collapse, or the degree of collapse for parts with varying geometry. This can be mitigated by experience and correlation with crash testing.

A.3.4 New constitutive law

New materials constitutive laws permit now to correctly represent failure taking into account tension or compression fields. Models must take into account this problem during the development of constitutive laws.

A.4 General recommendations for the mesh of Finite Element vehicle models addressed to crash simulations

A.4.1 General

This appendix contains recommendation that can be used to develop a FE vehicle model to be used during impact analysis against safety barriers.

A.4.2 2D-Mesh Specifications

A.4.2.1 General recommendations

As FE models used for crash tests usually directly impact only with a limited part of their body/structure against the obstacle (i.e. front body for front impacts or one side of the vehicle body for lateral or angulated impacts), it is a good habit to create a finer mesh only for the part of the vehicle's body which is directly involved in the impact. This can greatly improve both the crushing behaviour of the body and the contact definitions between the body and the obstacle. Due to the restricted zone where this finer mesh has to be done, this should not have a drastic effect on the time needed to complete the simulations.

Obviously, the same considerations can be done for the FE model of the road restraint system or the generic obstacle, as well. In particular, in the case of a roadside barrier, the steel rail or the other part of the restraint system intended to come in direct contact with the errant vehicle should be characterized by a finer mesh.

The element formulation and mesh size can have a great influence on strength of a part both at yield and post yield. It is well known that certain types of shell element in soften in response as their size decreases. This in turn will greatly influence accelerations.

If the element size is large enough to deviate significantly from the original geometry (chordal deviation) this can change the stiffness of the part. Also if the element size is too large to smoothly capture the deformed shape, the part will be overly stiff in its response.

The number of through thickness integration points in a shell can determine when a thicker part collapses in the analysis, quite possibly the time of the collapse is wrong.

When modelling a vehicle structure, the trim, seat components, door winder mechanisms/locks and other components are not represented. The missing mass, which is often in the region of 10 % - 20 % of the total vehicle mass, is distributed around the modelled structure. The accuracy or otherwise of how this is applied will affect vehicle inertias.

A.4.2.2 Criteria for the definition of geometric details

A.4.2.2.1 Holes and slots

The geometric parameters that define a hole are its diameter, D (or the maximum dimension of the slot) and the ratio L/D between the minimum dimension of the section and the diameter of the hole. These cases can be identified:

D <20 mm	The hole can be neglected
D = 20-40 mm	Mesh the hole with a square.
20 mm < D < 100 mm	L/D > 10 The hole can be neglected. L/D < 10 Mesh the hole with a radial, secant mesh, with at least five elements along the edge of the hole.
D > 40 mm	Follow the general mesh criteria.

A.4.2.2.2 Fillets and radii of curvature

The geometric parameters that define a fillet are its radius R and the ratio L/R between the minimum dimension of the section and the fillet radius. Theses case can be identified:

R < 10 mm	The fillet can be neglected. Trim the fillet by extending the mesh along the lines tangent to the edges of the fillet.
10 mm< R < 20 mm	L/R > 10 Neglect the fillet. L/R < 10 Mesh the fillet with a secant segment.
20 mm < R < 40 mm	L/R > 10 Mesh the fillet with 2 secant segments. L/R < 10 Mesh the fillet with 3 secant segments.
40 mm < R < 100 mm	L/R > 10 Mesh the fillet with 3 secant segments. L/R < 10 Mesh the fillet with 4 secant segments.
R > 100 mm	Follow the general mesh criteria.

A.4.2.2.3 Drawings and relieves

In general, neglect these features when smaller than 5 mm.

A.4.2.3 Mesh features

Metal sheets shall be meshed with four-node shell (plate) elements (capable of reproducing membranal and flexural stiffness) with linear formulation.

Three-node elements can be used for mesh consistency. Three-sided elements should not be more than 5 % of the total number of elements in the model and more than 10 % in a single metal sheet.

Mesh size	10 mm maximum mesh size in regions of contact, up to 10 mm to 20 mm in less significant areas. Up to 40 mm far from impacting points (example: car impacting with the frontal left side. The rear right side can be meshed with 40 mm mesh size)
Mesh Uniformity	Mesh should be as uniform and homogeneous as possible. The ratio between the dimensions of two adjacent elements should be less than 1,5 for boxes and 2 for panels.
Minimum number of elements	Elements dimension should not be greater than the welding pitch, with at least 3-4 elements between two adjacent spotwelds. For boxes and boxed beams: define at least 5 elements along each dimension.
Aspect Ratio	< 3
Warping	< 10 deg. < 5 deg. For 90 % of the total number of elements
Skewness	Minimum angle QUAD elements: 45 deg. for 95 % of the elements 40 deg. for 5 % of the elements

	Maximum angle QUAD elements: 135 deg. for 95 % of the elements 140 deg. for 5 % of the elements Minimum angle TRIA elements: 20 deg. for 95 % of the elements Maximum angle TRIA elements: 120 deg. for 95 % of the elements
Taper	< 0,5
Jacobian	> 0,55

A.4.2.4 Welding and connections

A.4.2.4.1 Spot-welding

Spot-weld shall be modelled with rigid or deformable links. The nodes to be connected should be facing each others as much as possible. The projection of the midpoint of two connected nodes should not draw more than 7 mm away from the measured theoretical position. The maximum distance between two nodes connecting two adjacent sheets should not be greater than 10 mm; in particular it should not be greater than 7 mm in the 80 % of occurrences.

Current vehicle manufacturer's standards suggest that spot welds should be modelled by using a deformable mesh independent element and not rigid beams connecting nodes in most cases.

A.4.2.4.2 Seam welding

The seam welding should be modelled by rigidly connecting the nodes in the weld.

A.4.2.4.3 Bonded joints

In case of structural adhesive materials or glues, the junction should be modelled with solid elements. It is admissible the use of 1-dof spring elements between coincident nodes. Adequate documentation should be provided for the computation of spring characteristics.

If the bonding has no structural function, it can be neglected.

A.4.2.4.4 Bolted joints

Bolts can be modelled with 1D-beam elements, evaluating the stiffness properties of the cross-section. The theoretical centres of head and nut of the modelled bolt shall be rigidly connected to the mean contact circumferences of the metal sheets to be jointed.

A.4.3 3D-Mesh specifications – Mesh features

Brick elements:

8-noded hexahedral	Preferred
Pentahedral	< 2 % of the total number of elements
Tetrahedral	< 0,1 % of the total number of elements

Critical regions in the mesh may require higher accuracy and the exclusive use of hexahedral elements.

Mesh size	5-10 mm
Details	Details of less than 3 mm dimension can be neglected.
Minimum number of elements	For thin-walled structures (thickness 3-4 mm) the maximum dimension of the elements is bound by the thickness. In other cases, at least two elements in the thickness should be defined.
Aspect Ratio	< 5 for 95 % of the elements < 10 for 5 % of the elements > 15 unacceptable
Face warpage	< 20 deg. for 95 % of the elements < 30 deg. for 5 % of the elements > 60 deg. unacceptable
Face skew	< 45 deg. for 95 % of the elements < 60 deg. for 5 % of the elements
Jacobian	> 0,6 for 95 % of the elements > 0,4 for 5 % of the elements < 0,3 unacceptable

Annex B

Recommendations and criteria for multi body vehicle models addressed to crash simulations

B.1 Introduction

Multi body models describe vehicles using a small number, if compared to fem models, of elements. Mass is concentrated in points where mass and inertia components of inertia tensor are specified. Masses are connected using deformable elements or cinematic joints. Deformable elements can represent physical elements, i.e. beams, cables, trusses or a sort of black box element (assuming for example the load-deflection history measured during an experiment).

Masses can interact through contact elements that will transfer loads inside the model between masses not necessarily jointed by deformable elements.

Multi body models of vehicles are strongly code dependent and global indications must take into account this problem.

B.2 General requirements

The model shall contain at least:

- rotating wheels;
- suspensions systems described according to the real suspension geometry of the vehicle;
- deformable frame described with several masses;
- engine representation;
- contact elements that give a good representation of the real shape of the vehicles. Contact elements located outside the real vehicle volume are not allowed;
- masses reference frame shall be carefully chosen taking into account inertia tensors properties.

B.3 Modelling requirements

Requirements for multi-body modelling

- engine can be modelled as one rigid body;
- frame shall be modelled at least with three bodies (frontal central and rear part);
- contact surfaces shall represent the real shape of the car.

Annex C

Test methodology

C.1 Components tests description

C.1.1 General

Simulated tests shall be performed on vehicle components to demonstrate the capabilities of the sub structures. Main tests are on front and rear suspension and the results should be compared with simple pendulum tests.

C.1.2 Isolated suspensions tests

The suspension system shall be extracted from the body of the vehicle (or the remaining part of the vehicle can be simply considered non deformable) and impacted by a pendulum to demonstrate the energy absorbing capabilities of the component. This energy absorbing mechanism shall demonstrate both the shock absorber behaviour and the failure of the system.

The pendulum shall have a kinetic energy capable of damaging the structure with a speed of 10 m/s. Impacts shall be performed in vertical longitudinal and lateral directions.

C.1.3 Suspension and handling simulations

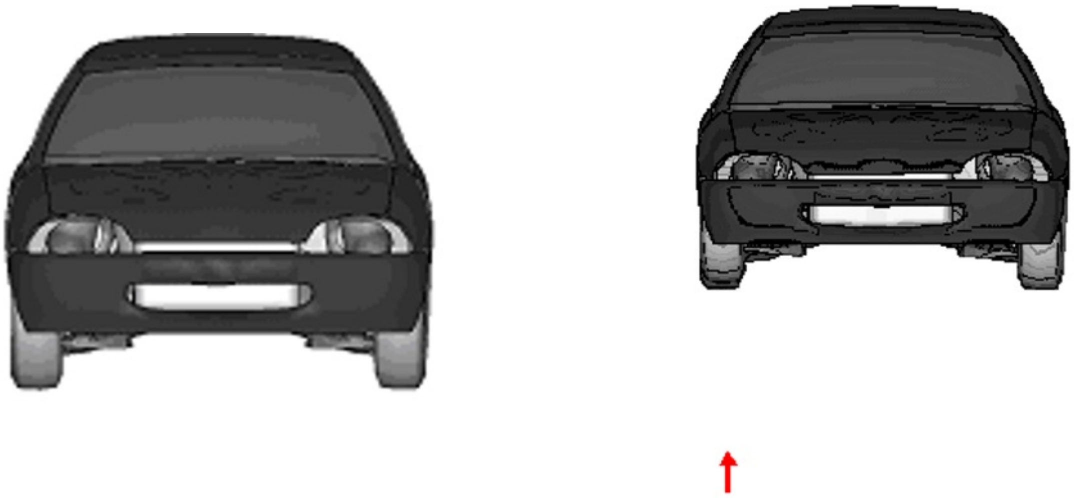
Simple simulations and correlations with experimental tests are required.

Each wheel shall be separately loaded with the vehicle suspended above the ground. A load shall be applied to a surface pushing the wheel up to the bottoming of the shock absorber (typical value of the applied force for a small car is around 4000 N). The movement of the wheel shall reflect the correct movement influenced by the characteristic angles of the suspension. In case of front independent suspensions, the steering movement shall be uncoupled from the shaking of the respective suspensions.

This phase includes 3 different test approaches:

- single load applied to every single wheel (test 1.2.1);
- symmetrical load applied to front and rear suspension system (test 1.2.2);
- non-symmetrical load applied to front and rear suspension system (test 1.2.3).

An example of single load test with a small car (GEO-Metro) is shown in Figure C.1; under this force the presence of a stabilizer bar implies a coupling between the two suspensions.

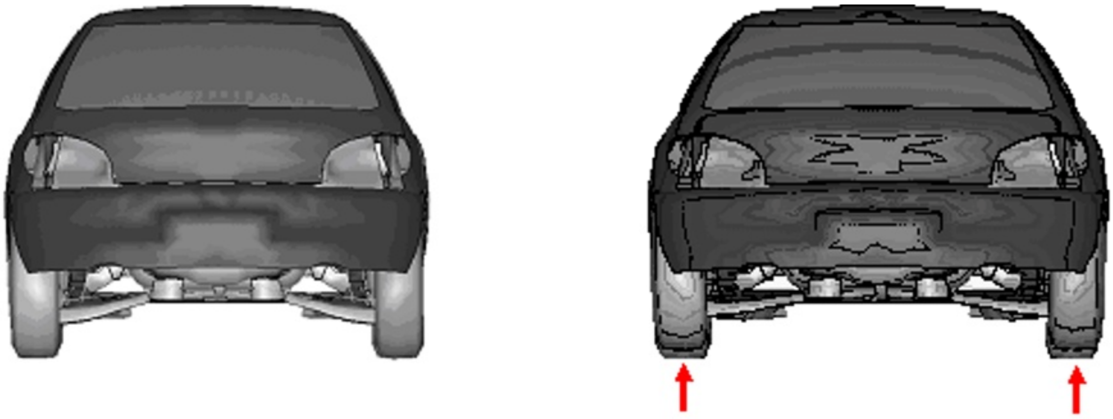


a) Initial position

b) Front right suspension compressed

Figure C.1 — Load applied to the single front right wheel

An example of rear suspension testing with symmetric loads is shown in Figure C.2 .



a) Initial position

b) Right suspensions compressed

Figure C.2 — Compression of rear suspensions wheels (symmetric loads).

C.2 Vehicle in idle

The vehicle must remain stable in idle for a time corresponding to the time needed for the simulation against the safety barrier.

C.3 Linear/circular track

C.3.1 General

The vehicle model is given an initial speed in a predetermined direction and its subsequent motion observed. The initial speed shall be equal to the speed that will be used during impacts against safety barriers.

C.3.2 Linear track

Linear trajectory with a constant longitudinal speed of 100 km/h shall be imposed on the vehicle (test 1.3.1)

The model shall be able to follow the above trajectories for more than 30 m.

C.3.3 Circular track test

Circular trajectory with same speed selected in test 3.1 shall be imposed on the vehicle. The vehicle should describe a circular trajectory with a diameter equivalent at the one that gives a lateral acceleration of 0,1 g (test 1.3.2)

This phase includes 2 different tests:

- With the vehicle at rest a load is applied to the steering system (for a small car, a torque of about 400 Nm should be enough). When the vehicle is given acceleration, (a value of 10 m/sec^2 for 0,3 second) it should start turning around. Removing the applied load, the vehicle trajectory should follow the direction tangent to the previous circular trajectory. (test 1.4.1)
- Vehicle with initial speed (25 km/h) and torques applied to steer the vehicle (a torque of about 200 Nm should be enough for a small car). After 0,3 s these loads are removed, the vehicle steering system should rotate back and the vehicle follow the direction tangent to the previous circular trajectory. (test 1.4.2)

The model shall be able to follow the above trajectories for more than 30 m.

C.4 Curb testing

The vehicle model is forced to override curbs to test the response of the suspension system and wheels to small impacts.

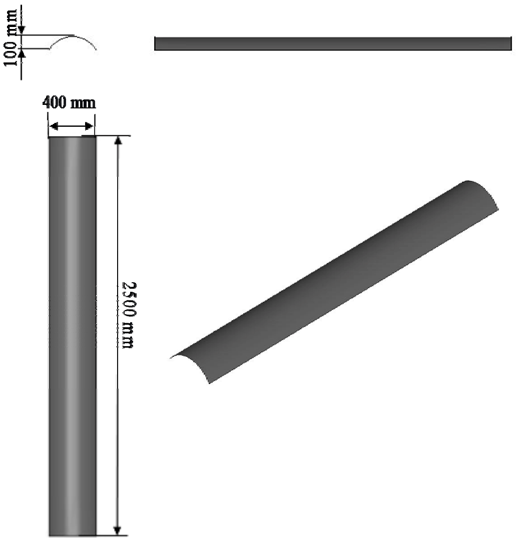


Figure C.3 — Curb for impact with both the two front or rear wheels

The vehicle shall impact with a speed of 15 km/h against a rigid curb with a circular section with the front and rear wheels.

Six tests shall be performed:

- both front wheels (test 1.5.1);
- both rear wheels (test 1.5.2);
- right front wheel (test 1.5.3);
- left front wheel (test 1.5.4);
- right rear wheel (test 1.5.5);
- left rear wheel (test 1.5.6).

The curb has to be modelled by with a spline curve, made of rigid shell elements and fixed to the ground.

The shape and dimensions of a typical curb are represented in Figure C.3. In case of an asymmetric impact the overall curb length may be shorter, provided that the curb is large enough for the hitting wheel.

C.5 Full-scale vehicle testing

In order to assess the global response of the vehicle, impacts of the vehicle model against a rigid wall in the different directions of impact for which the model has been developed should be simulated. (Test 1.6.1)

A further validation activity shall be carried out showing the behaviour of the model during impacts against deformable barriers (test 1.6.2). Two impacts against deformable barriers shall be reproduced. These case should be representative of the impact conditions for which the vehicle model has been modelled and should differ one from the other as much as possible (i.e: a vehicle model developed for frontal impact against crush cushions should be tested with two different cushions of diverse typology).

For the above simulations results shall be provided to demonstrate the capabilities of the model. Different results are required for the different simulations. In the following table these results are outlined.

The validation report shall comply with the format given in the Reporting Guideline and has to be included in the documentation enclosed with the vehicle model.

Annex D

Phenomena importance ranking table for vehicles

Deformable Components

	Characteristic to be described		*notes*	*Relevant Test*	*type of result expected*	*Import. (0-10)*
Element to describe						
General	Shape / dimension	External structures	High definition			9
		Internal structures	Low definition			6
	Mass		Accurately			9
	Mesh		Small enough to describe accurately the deformation in particular for external structures or part in contact with the VRS			8
	Stability		Running stability for high and low speed	Trajectory tests	Stability Suspension system Steering system	8
Suspension system	Modelling		Discrete element located correctly	Road map	DATA???	9
Steering system	Modelling		Check correct behaviour Steering angle	Road map	DATA???	9
Tyre	Modelling		Pressure evaluation Deformation	Full scale test	force / deflection Stress / strain curves	
Load	Dimensions Position Linkage Deformability		Real behaviour The load does not influence /limit the deformation of the frame			8
Axle	Failure and detachment		Pull out	Full scale test	Identify failure limit	7
Non structural components	Seats		Simple modelling	---	---	6
	Fluid		Identify quantities Can influence the general behaviour???			6 - 8
Instrumentations	place		Place For long vehicles connection			10
Dummy	contact		Between head and VRS			8

Rigid Components					
	Characteristic to be described	*notes*	*Relevant Test*	*type of result expected*	*Import. (0-10)*

Element					
Structures not directly involved in the crash (ex: Engine)	Geometry / Mass Precision	Need to be as accurate as possible. To guarantee the correct dynamic behaviour	-	-	6
	Mesh dimension	In accordance with the location			7
	Dynamic properties	Well described	Evaluation of the proprieties		8
Masses		Particular attention on how to connect the concentrate masses			8

Annex E

Phenomena importance ranking table for test item and vehicle interaction

	Characteristic to be described	*notes*	*Relevant Test*	*type of result expected*	*Import. (0-10)*

Characteristic					
Mesh	Dimension: in accordance with the vehicle used, limited to the impact area				
Friction	Always defined				
Mass scaling	Limited use <10%				
Constrain					
Contact					
Snagging					
Post impact inspections					

Bibliography

[1] EN 1317-1, *Road restraint systems — Part 1: Terminology and general criteria for test methods*

[2] EN 1317-2, *Road restraint systems — Part 2: Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets*

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

[4] EN 1317-5, *Road restraint systems — Part 5: Product requirements and evaluation of conformity for vehicle restraint systems*

[5] ENV 1317-4, *Road restraint systems — Part 4: Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety barriers*

[6] prEN 1317-4, *Road restraint systems — Part 4: Performance classes, impact test acceptance criteria and test methods for transitions of safety barriers and Removable Barrier Section* (under preparation)

[7] prCEN/TR 1317-6, *Road restraint systems —Part 6: Pedestrian restraint system, pedestrian parapets* (under preparation)

[8] prEN 1317-7, *Road restraint systems — Part 7: Performance classes, impact test acceptance criteria and test methods for terminals of safety barriers* (under preparation)

[9] prEN 1317-8, *Road restraint systems — Part 8: Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers*

[10] CEN/TR 16303-1, *Road restraint systems — Guidelines for computational mechanics of crash testing against vehicle restraint system — Part 1: Common reference information and reporting*

[11] CEN/TR 16303-3, *Road restraint systems — Guidelines for computational mechanics of crash testing against vehicle restraint system — Part 3: Test item modelling and verification*

[12] CEN/TR 16303-4, *Road restraint systems — Guidelines for computational mechanics of crash testing against vehicle restraint system — Part 4: Validation procedures*

This page deliberately left blank

British Standards Institution (BSI)

BSI is the independent national body responsible for preparing British Standards and other standards-related publications, information and services. It presents the UK view on standards in Europe and at the international level.

BSI is incorporated by Royal Charter. British Standards and other standardisation products are published by BSI Standards Limited.

Revisions

British Standards and PASs are periodically updated by amendment or revision. Users of British Standards and PASs should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using British Standards would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover. Similary for PASs, please notify BSI Customer Services.

Tel: +44 (0)20 8996 9001 Fax: +44 (0)20 8996 7001

BSI offers BSI Subscribing Members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of British Standards and PASs.

Tel: +44 (0)20 8996 7669 Fax: +44 (0)20 8996 7001
Email: plus@bsigroup.com

Buying standards

You may buy PDF and hard copy versions of standards directly using a credit card from the BSI Shop on the website **www.bsigroup.com/shop.** In addition all orders for BSI, international and foreign standards publications can be addressed to BSI Customer Services.

Tel: +44 (0)20 8996 9001 Fax: +44 (0)20 8996 7001
Email: orders@bsigroup.com

In response to orders for international standards, BSI will supply the British Standard implementation of the relevant international standard, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Knowledge Centre.

Tel: +44 (0)20 8996 7004 Fax: +44 (0)20 8996 7005
Email: knowledgecentre@bsigroup.com

BSI Subscribing Members are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.

Tel: +44 (0)20 8996 7002 Fax: +44 (0)20 8996 7001
Email: membership@bsigroup.com

Information regarding online access to British Standards and PASs via British Standards Online can be found at **www.bsigroup.com/BSOL**

Further information about British Standards is available on the BSI website at **www.bsi-group.com/standards**

Copyright

Tel: +44 (0)20 8996 7070
Email: copyright@bsigroup.com

BSI

389 Chiswick High Road London W4 4AL UK

Tel +44 (0)20 8996 9001
Fax +44 (0)20 8996 7001
www.bsigroup.com/standards

raising standards worldwide™