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Road restraint systems - Guidelines for computational mechanics of crash testing against vehicle restraint system - Part 3: Test Item Modelling and Verification

Rückhaltesysteme an Straßen - Richtlinien für Computersimulationen von Anprallprüfungen an Fahrzeug-Rückhaltesysteme - Teil 3: Modellierung des Prüfgegenstands und Überprüfung

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Foreword

This document (CEN/TR 16303-3:2012) 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]

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[1] In preparation

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Introduction

This part of this Technical Report is meant to provide the user with all the information necessary for the development of a complete and efficient numerical model of a test item vehicle in order to properly simulate a crash event.

The vehicle restraint system (VRS) models represent the test item in a certification test according EN 1317. The model shall faithfully depict the performance of a VRS so that the performance criteria identified in EN 1317 can be extracted from the simulation of a vehicle impact with the VRS model. The VRS simulation can only be assessed in combination with a validated vehicle model described in CEN/TR 16303-2.

There are different types of VRS and they can incorporate concrete, metal, plastic, and composite materials in their construction. Each system has different modelling requirements and the following manual describes the guidelines applicable for all VRS. It is important to recognize that the requirements for modelling a deformable VRS are significantly different from a rigid systems and the latter are not covered in this version of the guidelines.

This document currently focuses on Finite Element simulation methodologies. Rigid body (or multi-body) dynamic codes are also used in the development of a VRS. The VRS model requirements are not the same as for the Finite Element approach and shall be consistent to the methodology. The CM/E group does not yet have guidelines for the use of rigid body codes and their application for certification requirement cannot be recommended until they are similarly defined.

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1 Scope

The aim of this Technical Report is to provide a step-by-step description of the development process of a reliable VRS model for the simulations of full-scale crash tests.

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.

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

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

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

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

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

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

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

CEN/TR 16303-2:2011, *Road restraint systems — Guidelines for computational mechanics of crash testing against vehicle restraint system — Part 2: Vehicle Modelling and Verification*

CEN/TR 16303-4:2011, *Road restraint systems — Guidelines for computational mechanics of crash testing against vehicle restraint system — Part 4: Validation Procedures*

3 General considerations on the modelling technique

3.1 General

Particular attention shall be paid on the geometrical description of the contact areas of the VRS model. Proper geometry and material properties shall be used. The fixation of the VRS to the roadbed shall correspond to the test conditions reflected by the standard and the application of the VRS. Modelling of any soil, asphalt, concrete, etc. element should be documented. Simplifications as well as rigid soil conditions shall be justified through empirical or engineering analyses independent of the computer model.

The model shall include all significant parts, the connections between the parts, and appropriate boundary conditions.

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3.2 Finite Element and Multi-body approaches

3.2.1 General

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.

Once the VRS model has been built, it shall be validated with simple tests, such as component tests and then full-scale dynamic tests. Validation procedures are listed in a separate document (CEN/TR 16303-4). These validation tests ensure the global response of the model is appropriate and any simplifications of the model still reproduce the functionality of the system. Numerical stability of the model can be assessed during the validation process. Subsequently, the model can be used to simulate full-scale crash tests within the application areas accepted in EN 1317.

Furthermore Computation mechanics when validated can provide support in real life situations that are not described within EN 1317.

3.2.2 Finite Element guidelines

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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 shall 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 Finite Element modelling techniques are identified in Annex A. The most significant parts of the VRS shall be modelled explicitly with a detailed mesh. Simplifications of certain structures (bolts, slots, etc.) are acceptable if the appropriate functionality is incorporated. For example, bolted connections can be replaced by beam elements if the appropriate failure characteristics of the beam elements are incorporated.

3.2.3 Multi-body guidelines

The MB approach consists in modelling the VRS with a number of rigid bodies connected by means of joints with specified stiffness characteristics. When reliable and validated data are available, the MB approach is very useful to perform parametric studies or big test scenario, since the computational cost of the analysis can be dramatically less than that of the corresponding FEM analysis.

4 VRS model

4.1 Component to be modelled

The majority of elements in a road restraint system lend themselves to direct geometric digitisation in a FE or MB model. These elements are (but not limited to):

1) posts;

2) horizontal elements;

    a. metal beams;

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b. cables;

3) block-out beams / spacers;

4) bolted connections;

5) concrete elements;

6) soil.

General mesh specifications for FE method are listed in Annex A. These specifications are based on the date of publication (March 2006) level of simulation activities in research and product development. As general practice, the mesh size and arrangements shall permit the observed (or expected) deformed shape of the parts. Once a mesh specification has been determined, it becomes a practical issue to determine to which extent this mesh shall be applied to the entire test object. The level of detail required in the deformed parts may not need to be applied to all structures that are not subject to local buckling phenomena or other high stress gradients.

Recommendations for the development of Multi-Body VRS models, addressed to crash simulations method, are listed in Annex B.

4.2 Coordinate system

The model of the test article should be defined with a consistent coordinate system. The origin of the coordinate system may differ for the analyst's or system modelling requirements, but the orientation of the axis should follow the following principles:

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X axis oriented along the traffic face of the system for redirective features. Symmetrical structures (crash cushions) may use the axis of symmetry. The positive direction is in the direction of traffic flow.

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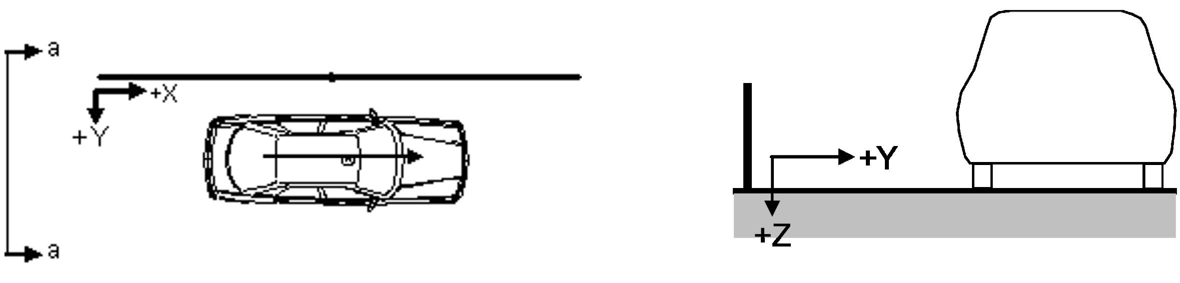
Y axis oriented normal to the X axis, parallel to the plane of the road with the positive direction oriented towards the traffic face of the structure.

Z axis oriented normal to the X-Y plane with the positive direction such that the X-Y-Z triad follows the right hand rule.

An example of the coordinate system for a safety barrier is shown in Figure 1. Note that that the origin of the coordinate system is moved away from the VRS for clarity.



a) Plan View

b) View a-a

Figure 1 — Vehicle Restraint System Coordinate Systems

The preferred units for the models are millimetres, newton, tons and seconds. These units guarantee consistency of results and are consistent with the vehicle modelling guidelines in CEN/TR 16303-2.

Nodal coordinates should be defined in the test article's reference frame.

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In case of FE models the fibre direction for all the shell elements should be coherent (same orientation, except in case of contact definition regions).

4.3 Material models

4.3.1 General

The types of materials used in the test article will define the type of material model definitions used in the simulation models. The material properties should reflect the properties of the actual part after manufacture. Thus representative specimen tests should be used as much as possible to represent the current state of the material properties.

4.3.2 Material modelling for dynamic finite elements simulations

The most common materials for test articles are steel and these materials lend themselves to commonly used material models. For example in LS-DYNA:

— **MAT_ELASTIC,*

— **MAT_PIECEWISE_LINEAR_PLASTICITY*,

— **MAT_PLASTIC_KINEMATIC*

Each material model has its own input requirements that should be obtained from laboratory tests of coupons or similar specimens from representative sections of the test article.

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Non-metallic materials that may be required to model a test item include concrete, plastic, wood, and soils. Material models are usually available in commercial programs. For example in LS-Dyna many non-metallic material models are provided with default parameters. It is strongly recommended that relevant laboratory tests of these materials are used to define input values.

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Documentation for soil models is available [Lewis]. Selection of soil modelling parameters should represent actual crash test conditions used for model validation. There may be occasions where the soil parameters should be selected in order to represent a critical design condition.

4.3.3 Material modelling for dynamic Multi-Body simulations

In MB technique elastic-plastic material properties are assigned to spring and damper elements at the hinges between rigid body elements instead of material models. Spring and damper elements shall consider nonlinearities such as plasticity, viscosity and load history as appropriate

5 Verification of the model

5.1 General

It is crucial that any simulation models used as part of a standardisation process are reproducible and repeatable. This requires that the model is numerically stable, i.e. it is not susceptible to divergent solutions and can complete the simulation run to the specified termination time. These conditions are a necessity for any analysis and are not special requirements for the CEN standards.

5.2 Basic Requirements

The computer files comprising the test article shall be arranged in such a manner that a 3rd party review is possible. This means than no encryption of data elements will be permitted in simulation models submitted for standardisation purposes.

The files and any computer scripts required to start the simulation shall be available for review by the Notified Body when required. If necessary, the simulation shall be run and witnessed by a Notified Body.

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Simulations shall not require restarts or parameter adjustments during the simulation process. Any input files to be qualified as reference information for the standardisation process shall result in stable simulation runs (no divergent solutions, termination errors, etc.). Any warning errors issued during the simulation shall be submitted with the simulation results for review.

For FE simulations limits for changes in the system mass (due to mass-scaling), hourglass energy, and total system energy are defined in CEN/TR 16303-4.

5.3 Model Verification and Proof of Performance

5.3.1 General

The numerical representations of the test articles shall demonstrate their capability to reproduce the crash performance in the EN 1317 test procedures. This shall be demonstrated through the reproduction of a documented crash test as well as other conditions listed in the following sections.

5.3.2 Finite Element Model

The function of critical components in the test item shall be demonstrated. All failed and strongly deformed components shall be reproduced using simulation and validated by component full-scale test. For example:

- Embedded posts: A quasi-static simulation of a single post shall be conducted for comparison with representative tests from the test facility. Post deflection and deformation behaviour shall correspond to the test results.

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- Bolted connections: A quasi-static simulation of a single bolted post connection shall be conducted for comparison with a representative test. Bolt and bracket deformation and fracture modes should correspond between the simulation and test results.

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The function of non-critical components: Suitable engineering analysis can be used to demonstrate model performance, particularly where the component is not a weak point in the structure.

5.3.3 Multi-Body Model

Depending on the used MB code, for the interconnection structure with several closed chains additional kinematical equations have to be provided to solve the general coordinates for the holonomic and nonholonomic constraints. There exist some different numerical techniques which support the build-up of the loop closure equations, see i.e. Hiller or Kecskeméthy.

The multi body model has to be validated with equal requirements and limits as the finite element model.

5.4 Full-scale dynamic testing and Simulated Crash Testing

The simulation model should be able to duplicate the crash performance required in EN 1317. These test protocols identify vehicle and test article performance parameters that shall be exported from the simulation model. The validation procedures for these test conditions are specified in CEN/TR 16303-4.

The test object models shall demonstrate the proper representation of the mechanical structures of interest. This shall be demonstrated by a report of the stress/strain behaviour in case of FE technique or of the load/deformation behaviour in case of MB technique for all deformable components. This information shall be compared to the material properties to verify that unrealistic loads are not transferred within or between parts. Examples of unacceptable model behaviour are bolts without failure criteria, metal structures experiencing stress beyond the ultimate limit, etc.

The test article components will be monitored during the validation procedure and final Type Test Simulations and any material stress / strain or load/deformation values that exceed accepted failure conditions shall be reported. Only stress / strain or load/deformation data for the test item need be reported. Components with excessive stress / strain or load/deformation data that can be justified (not part of critical components, deformations after period of interest, etc.) shall be documented so that 3rd party reviewers can determine if this behaviour is acceptable for the model behaviour.